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IMPERIAL BUREAU OF ANIMAL NUTRITION

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The Efficiency of Farm Animals in the Conversion of Feedingstuffs to Food for Man

BY

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IMPERIAL BUREAU OF ANIMAL NUTRITION
ROWETT INSTITUTE, BUCKSBURN, ABERDEEN, SCOTLAND

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THE EFFICIENCY OF FARM ANIMALS IN THE CONVERSION OF FEEDINGSTUFFS TO FOOD FOR MAN

INTRODUCTION.

THE question of the efficiency with which different farm animals convert feedingstuffs into food for man may be approached in different ways. Every practical feeding test is, in some respect, a contribution to the answer, but the first concern of the producer is the money economy of the process, not the material economy. For this reason there are very few feeding trials of which the records are given, or indeed kept, in such detail as would permit a study of the material economy to be made. To do this requires not only the assembling of accurate and detailed data on feed consumption, liveweight gains and yield of milk or eggs, over stated intervals, but also a knowledge of the amount and composition of the edible food products. Milk and eggs vary so little in their composition that average analytical values may with confidence be assigned to them. When the product whose composition is to be assessed is " meat " of any kind the estimation is more complicated. The composition of liveweight gain varies with age. In the mature fattening animal, the gains are almost entirely edible matter and as fattening proceeds the gain approximates more closely to pure fat. Gains in the growing animal contain less edible material, since growth of bone and other inedible tissues is taking place, and the edible material contains relatively more water and protein and less fat. Further, the ratio of carcase to liveweight and of edible matter to carcase weight varies with age and stage of fattening in each species.

Again, accurate and detailed records of the type required are not likely to be available except from large farms practising scientific animal husbandry, or from research centres. There the animals will usually be rationed in accordance with theoretical requirements and, if the theoretical basis be correct, their efficiency will approximate to that which would be deduced from an examination of the theoretical basis itself.

The results of feeding experiments frequently give rise to criticisms of the standards used, usually when the animals prove more efficient than was to be expected. Accepted standards may be shown by new fundamental research to be in error. Yet, in so far as practice is already to a considerable extent and will be increasingly based on theoretical standards, the simplest and most direct approach to the problem of efficiency of conversion would appear to be through feeding standards and the records of experiments based on them. Other practical trials which provide data are usually tests in which the animals have been fed to appetite or at an arbitrary level of feed intake below what they would eat if unrestricted.

The fundamental research by calorimetry and metabolism experiments on which feeding standards are based must obviously afford valuable data on the efficiency of animals as converters of feed and the conclusions to be derived from that work will be discussed. But, for reasons which will be indicated, these conclusions are not, in all cases, directly applicable, to the problem to be considered here, which is the efficiency of production of food for man.

FUNDAMENTAL RESEARCH.

The basic studies of feed utilisation by farm animals have been either almost purely academic studies in comparative physiology or designed for use in the formulation of feeding standards. The former may, of course, be used for the same purpose as the latter. They

include estimation of the maintenance energy expenditure (basal or standard metabolism + energy expenditure on feed-getting), the energy expenditure during growth and fattening, milk production and egg laying, and the protein requirements for these several processes. The results and their implications may be summarised as follows :—

Basal or Standard Metabolism.—The energy expenditure, when an animal is at rest and neither digesting nor absorbing food, increases with bodyweight and at a rate which is proportional to a power of bodyweight of the order of 0·73. It follows that the expense of maintaining life is less, per unit of bodyweight, for large than for small animals.

Maintenance Expenditure.—Maintenance energy expenditure includes the expenditure on feed-getting. It will, therefore, vary greatly according to the conditions of the test. The stall-fed animal will expend relatively little ; the animal on poor grazing will have a very high expenditure ; one tethered on good pasture will be intermediate. Indeed, it is well known that an animal on poor grazing may have to move about so much in search of feed that it does not procure even a maintenance ration. The difference between the stall-fed animal and that on pasture consists only partly in the expenditure on movement. Ritzman and Benedict (1938) have found that pastured animals show a significant rise in basal energy expenditure over that determined during stall-feeding.

Production.—The study of production requirements was based largely on the work of Kellner. He compared the value of different feeds for production of liveweight increase in mature oxen by giving a basal ration sufficient or more than sufficient for maintenance and then adding a known amount of the feedingstuff to be tested. The gain in weight of fat due to this addition was the measure of its value. Comparison with the fat gain due to the same amount of starch gave its origin to the term " starch equivalent." It is unfortunate that this method of expressing feeding value should so rapidly have passed into general use in Europe and should still persist. The technique itself is open to criticism on several grounds, and more recent work has shown, not only that certain assumptions made in calculating the results were false (Kleiber, 1935) but that the values of feedingstuffs for the fattening of mature oxen are not the same as their values for other purposes (Møllgaard and Lund, 1929 ; Morrison, 1937). The result is that, although more accurate determinations of feeding value by calorimetry and balance experiment have since been made and the values are known in terms of energy units (Calories), it is still customary to recalculate them in terms of " starch equivalent " or, in Scandinavian systems, in " net calories for fattening " or " feed units " which are similar in principle. This would lead to a great deal of confusion but for the device of expressing *all* requirements in terms of S.E. Thus, for instance, a quantity of feed sufficient to provide 1000 Calories for use in maintenance or in milk production will produce only 830 Calories in liveweight increase of oxen, according to Møllgaard, and less than 800 according to Forbes *et al.* (1926), and others quoted by Armsby and Moulton (1925). In formulating feeding standards in terms of S.E. these differences are taken into account.

Similar differences have been found in the comparison of pigs with bullocks. Breirem (1935) found that to produce 1000 Calories in liveweight increase of a fattening pig requires only 77 per cent. of the S.E. required to produce the same gain in a bullock. In pigs also the value for fattening is only about 80 per cent. of the value for maintenance.

These results together show that (1) the cost of maintenance of the pig is relatively greater than that of the cow or bullock, and (2) the efficiency with which energy available above maintenance requirement is converted into milk energy, or the energy of liveweight increase in pigs, is 20 to 30 per cent. greater than that with which liveweight increase is produced in the fat bullock. But, from the point of view of human food, these results are not strictly comparable because the whole of the milk is utilised as human food but only part of the liveweight increase. Nor do they satisfactorily assess the practical efficiencies of the animals because (*a*) the time taken to produce 1000 Calories in milk may not be the same as that to produce 1000 Calories in fat beef or bacon and so the overhead charges for

maintenance may be different ; and (*b*) the production of liveweight increase in the fat animal is but the final process, following on growth, which leads to only one harvest of meat, while the cow's productive life includes more than one lactation, with a similar number of calves, and she is herself utilised as beef, so that the incidence of the overhead charges for rearing may be widely different. The superiority of 20 to 30 per cent. has reference to the comparison of two physiological processes in the same animal species, or of the same physiological process in two different species. It can not be taken to indicate the relative efficiencies of what are, in fact, different systems of production of human food.

FEEDING STANDARDS.

If then, the approach to the question of efficiency is to be through feeding standards, it is necessary to enquire what measure of accuracy these standards are likely to possess. The ration for a producing animal must supply the energy required for maintenance and an amount proportional to that of the product. The accuracy of the standard proposed will, therefore, depend on the accuracy with which (*a*) the energy supplied by the ration, (*b*) the energy required for maintenance, and (*c*) the energy of the product and that required to produce it can be estimated. In practice, these may be estimated simultaneously in the same experiments and, therefore, an error at any one step will affect the general deductions. The entire process may be presented thus : the total energy (heat of combustion) of the ration *less* the losses in undigested feed = the gross digestible energy (G.D.E.) ; this *less* the losses in fermentation gases (methane) and in urine = metabolisable energy ; this *less* the loss as heat = net energy and should be exactly equal to maintenance expenditure + the energy value of the product.

Total and Digestible Energy.—The total energy of the ration can be determined with great accuracy, but is not a satisfactory measure of its feeding value since, for example, it includes the energy value of substances like woody fibre which are not digested. The gross digestible energy can also be determined with great accuracy for any given ration or the feeds composing it separately. But it has been shown that the amount digested of a composite ration is not necessarily the sum of the amounts digested when the several components are tested separately. A composite ration may be better balanced than some or perhaps any of the component parts and, if so, the digestibility may be higher. When the digestibility of a single component is determined by difference, the result will be an overestimate if the added substance improves the balance of the ration, the general improvement being credited to the substance under test. If the addition disturbs the balance of the ration, the result will be an underestimate. A true result can be got only when the balance is correct and is not altered beyond definite limits by the addition. This aspect has recently been discussed by Mitchell (1937) and by Forbes, Bratzler and French (1940).

The digestibility of a ration may also be affected by the amount of fibre it contains and by the plane at which it is fed. Axelsson (1939, *a*) considers that digestibility in ruminants is highest when the percentage of crude fibre in the diet is between 18 and 23. Overfeeding depresses the digestibility of some constituents. Brody and Procter (1933) estimate that between maintenance and full feeding the total loss of ingested energy may be increased by up to one third. In view of these findings it is possible that many of the published figures for the digestibility of feedingstuffs may be inaccurate. On the other hand Watson, C. J., *et al.* (1935-1940), in an extensive series of experiments, have found no significant associative effect on digestibility from mixing roughages and succulents or cereals and protein concentrates and no marked effect on digestibility when similar rations were fed at levels from half-maintenance to full feeding.

There appears to be little individual variation in digestion by ruminants. Ritzman and Benedict, working with dry cows, on a plane of nutrition slightly above maintenance,

say that the digestibility of a given ration shows a maximum difference of 3·2 per cent. of the lowest value in the same animal at different times or with different animals at the same time. The variation due to the animal in Watson's series of experiments was also extremely small.

The digestibility of certain feedingstuffs differs to some extent with species. In the "improved" type of pig that is reared on high concentrate rations, digestibility rapidly decreases with increase of fibre in the ration (Axelsson, 1939, *b*). The optimum level is not well defined but is very low in comparison with ruminants. With rations low in fibre, however, pigs do not differ significantly from ruminants. Fowls are also said to differ somewhat from ruminants in their digestive processes (Ministry of Agriculture, 1936; Axelsson, 1937).

Metabolisable Energy.—In metabolism experiments the deductions to be made from digestible energy for losses in methane and in urine can be accurately determined and the range of individual variation is, according to Ritzman and Benedict, again for dry cows, not more than 5·6 per cent. of the lowest value. Increase in the plane of nutrition to full feeding may, Brody and Procter (1933) say, increase these losses by about one third.

To calculate the metabolisable energy of a ration when the amounts of the digestible nutrients are known, Wood (1924) used fixed conventional deductions. Taking the heat of combustion of the digestible protein as 5·8 Calories per gram he deducted 1·1 for incomplete combustion; from the heat of combustion of fat, 9·3 Calories per gram, he deducted 0·50 [1] for the lower heat value of lipoids included in the value derived by the usual method of analysis, and from the Calorie value of 4·1 for a gram of carbohydrate he deducted 0·34 for loss as methane. These values give a conventional figure of 3·76 Calories per gram or 1707 Calories per lb., as the metabolisable energy of the digestible nutrients (as starch). Ritzman and Benedict have shown, however, that the energy value of the losses in urine varies widely, that losses of non-nitrogenous energy occur, at least in pasture-fed animals, and that the nature and magnitude of the losses depend on both the nature of the diet and the plane of nutrition. Further, the losses as methane have recently been shown by Bratzler and Forbes (1940) to be closely correlated with the digestible carbohydrate intake. And, finally, ruminants lose a much larger proportion of digestible energy as methane than do pigs (Breirem, 1935). For these reasons it is not considered desirable to express the energy value of the rations to be considered here in terms of metabolisable energy by the use of conventional values, which would not necessarily be applicable to these rations and, even if they were, would make it impossible to use the results for comparison of the efficiency of ruminants and pigs.

Net Energy.—The determination of the net energy value of a ration is even less easy. The remaining loss to be determined is the heat generated. According to Hamilton (1935) the "thermogenic action" of a ration will be less the more perfectly balanced it is. There appears to be a protein optimum at which heat loss is least, and other components may be shown to have similar optima. Mitchell (1935, 1937) says that for each constituent and each purpose there is a range within which the diet is balanced. These will not necessarily be the same for different classes of animal. There are definite optimum levels of protein intake for different purposes. For maintenance the level of protein intake is about optimal when it provides 10 per cent. of the energy (Brody, 1935; Møllgaard and Lund); for growth and milk production between 15 and 25 per cent. (Møllgaard and Lund). The protein optimum for meat production has not been closely defined but it will be shown later that it is possibly of the same order as for milk, in the actively growing animal, and of the same order as for maintenance during the fattening period.

Further, the net energy is used for three purposes: maintenance, which includes basal

[1] This correction is not properly applied since it has been applied to the digestible fat on the assumption that the non-fat lipoids of the ether extract are digested to the same extent as the true fats. This assumption has recently been shown by Hale, Duncan and Huffman (1940) to be entirely incorrect. On their figures for digestibility the Calorie value of 9·3 per gram of digestible fat is approximately correct.

metabolism and feed-getting, and production. Since the basal metabolic rate of the same cow may vary by as much as 80 per cent. (Ritzman and Benedict), and since the maintenance requirement will vary in parallel, it is obviously impossible to predict, with certainty, the amount of milk which a cow will produce from a ration calculated to yield a given amount of net energy. If the maintenance expenditure allowed be at the higher limit of variation, and the basal metabolism during the experimental test is less than this, the ration may be extravagantly high as judged by the actual milk yield. If the maintenance allowance be in accordance with the mean basal metabolic rate the actual milk yield may be above or below that for which the production requirement was calculated. There are also wide, apparently genetic, differences in the efficiency with which animals utilise net energy. Yet Ritzman and Benedict consider that the net energy value of a ration can be predicted, for dry cows, with an average error of not more than 36·4 per cent. of the lowest value and since feeding standards are based on net energy value (which, with the provisos outlined above, is the same thing as starch equivalent), it might be suggested that production, based on theoretical feeding standards determined in this way, will probably not exceed nor fall below expectation by more than this amount in individual cases and will, on the average, deviate from expectation by very much less than this. That is to say on the average, the energy value of the product as a percentage of the available energy of a ration calculated from feeding standards, will not be expected to err by more than $\pm$ a sixth.

There are many details in these complex relationships which still require study, but the general implications are well understood. Feeding standards are usually formulated in terms of protein as well as S.E. so that the proportion of the energy supplied by protein may be approximately optimal, and the balance of the ration in other respects receives attention within the limits of present knowledge. On theoretical grounds, therefore, no significant difference would be expected between estimates of efficiency based on the standards themselves, and those derived from practical experiments in which the animals have been rationed on the basis of feeding standards.

THE BASIS OF COMPARISON.

The efficiency with which animals convert feedingstuffs into food may be expressed either as "partial efficiency," *i.e.* the efficiency with which they convert the production ration, or as "total efficiency," *i.e.* the efficiency with which they convert the ration as a whole. The latter has more practical interest than the former since it takes into account differences in maintenance requirements. Nor is it always possible to separate maintenance from production rations. Where such a separation has been possible, *i.e.* for milk and egg production, it has been made in the analysis which follows.

In order to make a satisfactory comparison between feed consumption and yield of human food, both should be expressed in the same unit or in units which make the values comparable or have some special significance. Units of fresh weight offer an unsatisfactory basis since both rations and products differ widely in their water content. Weight of dry matter may be used as a first rough basis but is also unsatisfactory because rations and products of similar dry matter content may differ greatly in nutritive value. Comparisons on the basis of energy and protein supply would be of much greater significance.

Rations.

Armsby and Moulton, after an extensive survey of digestion and metabolism, chiefly in ruminants, have estimated the efficiency of conversion of feed to certain products in terms of energy, using "gross" (heat of combustion) energy in both cases. It is difficult to understand why they should have chosen this basis since the total energy of a ration gives no true

indication of its feeding value. Brody and his associates have made extensive studies of efficiency by expressing feed consumption first in pounds of total digestible nutrients (T.D.N.), calculated as protein + carbohydrate + fat × 2·25, and then assigning to one pound of T.D.N. the average value of 1814 Calories. In his earlier writings Brody refers to this value simply as the energy value of 1 lb. T.D.N. It was, therefore, assumed, at first, that this was intended to represent digestible energy, "starch" being taken as yielding 4 Calories per gram. In a recent review of his own and other work (1939), however, he refers to it as "the metabolisable energy" of the ration, and says that values for metabolisable energy from the literature vary from 1600 to about 1800 Calories per lb. T.D.N. It has already been noted that Wood used a conventional value of 1707 Calories. In Ritzman and Benedict's experiments on cows, the metabolisable energy of a number of different rations was between 77 and 90 per cent. of the digestible energy. This would be roughly equivalent to from 1430 to 1670 Calories per lb. T.D.N. Forbes and Kriss (quoted by Kriss, 1931) found that average mixed rations gave a value of 1616 Calories of metabolisable energy per lb. T.D.N. Brody's assumption of 1814 Calories per lb. of T.D.N. would appear, therefore, to be too high for metabolisable energy and his estimates possibly very slightly overestimate efficiency in terms of digestible energy, or considerably underestimate it in terms of metabolisable energy. In the discussion of his results below, it is assumed that they are comparable with ours, *i.e.* in terms of digestible energy.

To avoid the use of such conventional values, where comparisons are made on the basis of rations, the gross digestible energy (as starch) of the rations has been calculated from the Ministry of Agriculture (1939) tables of composition of feedingstuffs and compared with the energy of the product derived, by applying to G.D.E. the value of 4·1 Calories per gram (1860 Calories per lb.) and using the energy values of 4·1 Calories per gram of protein and carbohydrate and 9·3 Calories per gram of fat for the products. This procedure is simple and seems to avoid the introduction of complications which would not necessarily increase the accuracy. It has the advantage of expressing the food products in the terms normally used in studies of human diet. A direct comparison has also been made between the protein equivalent (P.E.) of the ration and the protein produced.

Since digestibility coefficients for pigs and poultry are not always the same as for ruminants, the results for these animals will be subject to a slight error, but, since only normal rations of optimum digestibility for them have been used, the error introduced in this way will be insignificant.

In addition it is of both practical and theoretical interest to know with what efficiency animals function in the production of fat. Most feedingstuffs contain little fat and both requirement for and tolerance of fat appear to be low in farm animals. Since it is uneconomical, in both money economy and energy economy, to feed more protein than is required, the aim in planning rations should be to have enough but no surplus of protein. It is legitimate, therefore, to compare the amount of fat produced with the amount of non-protein digestible nutrients supplied, or to compare the energy values of these.

Choice of Standards.

This study of efficiency is primarily concerned with feeding practice in the United Kingdom. The standards on which it is based are therefore, wherever possible, those recommended by the Ministry of Agriculture. When their recommendations have been too indefinite or incomplete, they have been supplemented by reference to other publications and by consultation with Mr. A. Crichton, Head of the Duthie Stock Farm of the Rowett Research Institute and members of his staff, with whose assistance representative feeding histories have been built up for the lives of cattle, sheep, pigs and poultry.

No extensive comparison of different standards has been made but some points of special

interest have been selected for study. For instance, it is frequently stated that the Scandinavian standards for milk production are more economical than those in use in this country. A tabular comparison of standards for milk production is, therefore, presented (Table I) and the detailed calculations for milk production include a comparison of the Ministry's with Møllgaard's standards (Tables VIII and IX). There is no significant difference between this Danish standard and the slightly lower Swedish standard of Hansson.

TABLE I.

FEEDING STANDARDS FOR MILK PRODUCTION.

Maintenance			Production			
Liveweight	S.E.–lb.	P.E.–lb.	Milk Yield.	Fat per cent.	S.E.–lb.	P.E.–lb.
Ministry of Agriculture (England).						
10 cwt. 11 cwt.	6·5 7·0	0·70} 0·75}	1 gallon	3·5 to 3·8	2·5	0·60
Møllgaard (Denmark).						
10 cwt.	5·4	0·55	20 " milk units " = 61·28 lb. *i.e.* per gallon.	 3·5 to 3·8 3·5 to 3·8	 14·8 2·4	 3·72 0·60
Hansson (Sweden).						
		Digestible Protein				Digestible Protein
10 cwt.	5·06	0·55	1 gallon	—	2·4	0·45
Morrison (U.S.A.).						
	T.D.N.	Dig. Crude Protein			T.D.N.	Dig. Crude Protein
1000 lb.	7·925	0·70	1 gallon	3·5 to 3·8	2·84 to 3·16	0·49 to 0·61
See also review by Kriss (1931).						

Pregnancy Allowance.		
	S.E.–lb.	P.E.–lb.
Ministry of Agriculture (England).		
Total allowance for 3 months	91·0	27·3
Møllgaard (Denmark).		
1 Milk Unit daily for second half of pregnancy = total allowance of .	101·4	25·5

A good deal of attention has been given recently to the question of whether or not animals produce liveweight increase more efficiently when full-fed or when fed at some arbitrary level less than this. Comparisons have, therefore, been made from the records of experiments on pigs and poultry, expressing the result for pigs in terms not of liveweight increase but of food production. The experiments on poultry have been concerned with egg production and the results are therefore in terms of food.

In a few other cases, comparison has been made between Ministry rations and American rations. American standards have been included in the tabular summary for milk.

The Composition of the Product.

Milk.—The Scandinavian standards for milk production are expressed in terms of fat corrected milk (4 per cent. fat). The Ministry of Agriculture (1939) gives a table of standards for milks of different fat content. In all the calculations it has been assumed that the percentage composition of the milk concerned has been as follows: protein, 3·4; fat, 3·5; lactose, 4·8; and dry matter, 12·4. The requirements have been adjusted accordingly.

Beef and Veal.—The values used for beef have been taken from Wood and Newman (1928). Carcases or groups of carcases have been selected as corresponding to the liveweights in question when the appropriate killing out percentages (Hankins and Titus, 1939) are applied. No recent analyses of veal calves, of the size desired, could be found and those given by Haecker (1920) have been used.

Plimmer's (1921) analyses of offal have been used to assess the composition of edible offal from beef cattle and Haecker's records have been used for veal.

Sheep.—Few analyses of sheep carcases have been made. The extensive work of Hammond (1932, 1940), in which the composition is expressed in terms of " fat " and " lean," cannot be used. Those of Wood (1927), on which the feeding standards adopted by the Ministry of Agriculture were presumably based, have therefore been used. Calculations of the value of edible offal have been adapted from Plimmer's analyses.

Pigs.—The detailed estimates of efficiency in pork and bacon pigs have been based on recent experimental data from the Rowett Research Institute (unpublished) and other centres. Analytical data of sample pigs from the Institute experiments were available and, in the absence of other suitable data, were used in the bacon calculations. Edible offal was again assessed from Plimmer's analyses and information from the local Bacon Factory on the amount of lard obtained from representative animals. The composition of pork was assessed from data of Warner, Ellis and Howe (1934).[1] Mitchell and Hamilton's (1929) analyses of weanling pigs have been used.

Poultry.—The composition of a standard 2 oz. egg has been taken to be: protein 6·8 g., fat 5·5 g. and dry matter 12·5 g. (Kon, 1940). The yield and composition of edible material from table poultry has been computed with slight adjustments from the analytical data of Harshaw (1938).

Efficiency of the Total Stock Population.

As a check on the individual calculations, and because of its intrinsic interest, an attempt has been made to estimate the efficiency of conversion of feed crops to human food by the stock population during one year. This involves numerous complications which do not arise in relation to the separate functioning of individual animals. The overhead charges are increased by the maintenance of the breeding stock. Assumptions regarding average productivity, the losses which accrue from disease and average feeding and slaughter practice must be made. An account of these is set out in the Appendix.

[1] This particular value was chosen, after many trials, as that giving the most reasonable value when compared with the analyses of the bacon pigs. Neither Plimmer's data nor Mitchell and Hamilton's figures could be used because the total edible protein content of the 160 lb. pig was so high when estimated on either of these bases that it either already exceeded that of the 220 lb. Rowett Institute pig or allowed an insignificant margin for 60 lb. of liveweight increase. It is possible, however, that the value used errs somewhat on the opposite side. The reasons for this belief are set out on pp. 39 and 40. Had all the calculations for pigs been based on the ascertained feed consumption and the average analyses of American pigs as given by Hankins and Titus or Mitchell and Hamilton, the estimate of efficiency would not be materially different.

SUMMARY OF CALCULATIONS FOR INDIVIDUAL ANIMALS.

In order that the method of estimation of efficiency may, in all cases, be clearly understood, a representative series of the primary calculations is presented in full in the tables. Additional calculations on the same pattern have been made and the results are summarised in Tables XXIX and XXX. Instead of comparing the standards for requirements in terms of S.E. and P.E. with the yields of energy and protein in the product, typical rations, which had been drawn up to conform to the standards, have been chosen and the composition calculated in detail from the table of analyses given by the Ministry of Agriculture (1939). This makes it possible to estimate efficiency in terms of dry matter, protein, fat and energy (as Calories).

Table II.

DAIRY COW.

Ministry Ration for 11 cwt. Cow giving 4 Gal. Milk: Grazing Only.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
Feed Consumption.						
Maintenance 60·6 lb. grass .	12·1	2·5	0·4	6·0	10·3	8·9
Production 68·0 ,, ,, .	13·6	2·8	0·5	6·7	11·6	10·0
Total	25·7	5·3	0·9	12·7	21·9	18·9

	Total.	Production.
Calories	40,734	21,576
Non-protein digestible nutrients, lb. . .	14·8	7·85
Cals. from protein[1]: 32·4 per cent.		

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Products.					
Milk, 4 gal. . . .	4·96	1·36	1·40	1·92	12,006

Efficiency per cent.	D.M.	Energy.	Prot.	Fat.
Total	19·3	29·5	25·7	9·5
Partial	36·5	55·6	48·6	17·8

Milk Production.

The efficiency of milk production has been estimated for a winter ration of hay and concentrates[2] as given by the Ministry of Agriculture: for a grazing cow, and for a ration (Danish) of roots, straw and concentrates. These cover common practice and may, therefore, be taken as a reasonable guide to the efficiency of milk production. In all the calculations it is assumed that the weight of the cow remains constant (Tables II to VII).

[1] In all cases this refers to the total ration.

[2] It should be noted that the ration of hay suggested is adequate in protein but slightly deficient in S.E. for maintenance of an 11 cwt. cow according to Ministry theoretical requirements. The alternative rations of roots and hay do not provide a better basis if limited to the dry matter intake recommended.

For comparison with these calculations, based on feeding standards, the estimates of Brody and Procter (1935) and Brody and Cunningham (1936) of energetic efficiency, arrived at by mathematical treatment of American herd records; those of Edwards for show cows in this country, computed from Brody and Ragsdale's (1935) nomogram, and estimates made by us from the data of Axelsson (1940, *b*) for recorded Swedish herds have been collected in Table XI. Brody's computations are based on the heat of combustion energy value of milk and the value of 1814 Calories per lb. T.D.N. The figures in brackets are the originals: the others give the efficiencies recomputed to our basis. Further comparisons were sought

TABLE III.

DAIRY COW.

MINISTRY RATION FOR 11 CWT. COW GIVING 4 GAL. MILK: WINTER RATION.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Maintenance.						
16 lb. hay (good meadow) .	13·7	0·74	0·16	6·5	7·8	5·9
Production.						
3·25 lb. palm kernel cake .	2·9	0·55	0·17	1·4	2·55	2·4
3·25 ,, decort. gr. nut cake	2·9	1·34	0·22	0·7	2·85	2·4
6·50 ,, maize . . .	5·7	0·50	0·18	4·2	5·20	5·0
Production	11·5	2·39	0·57	6·3	10·6	9·8
Total	25·2	3·13	0·73	12·8	18·4	15·7

	Total	Production
Calories	34,224	19,716
Non-protein digestible nutrients, lb. . .	14·48	7·61

Cals. from protein: 21·3 per cent.

PRODUCTS. See previous table.

EFFICIENCY PER CENT.	D.M.	Energy.	Prot.	Fat.
Total	19·7	35·1	43·5	9·7
Partial	43·1	60·9	56·9	18·4

with the data of metabolism experiments, other than those on which the standards themselves were based, and of recent feeding tests. The results of the eight experiments of Ritzman and Benedict with four cows on different rations and at different stages of lactation are summarised in Table XII. From examination of the records of many feeding experiments only the few collected in Table XIII were found to give sufficient details of feed consumption to make a computation of efficiency possible and, even in these, an average composition of the milk had to be assumed. Certain points of major importance stand out from comparison of these data.

TABLE IV.

DAIRY COW.

WHOLE YEAR: AUTUMN CALVING: MINISTRY STANDARDS.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Winter Ration.						
Maintenance, 213 days	2918·1	157·6	34·1	1384·5	1661·4	1256·7
Production, approx. 520 gal. milk	1499·0	311·5	74·3	821·2	1381·7	1277·4
Grass (good), 91 days [1]	2338·7	482·3	81·9	1155·7	1992·9	1719·9
,, (poor), 61 days	952·8	83·4	7·1	500·2	619·3	543·1
Pregnancy allowance, 61 days	82·9	17·1	3·1	40·9	70·8	61·0
Total	7791·5	1051·9	200·5	3902·5	5726·1	4858·1

Calories, 10,650,546. Non-protein digestible nutrients, lb., 4363·7.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Milk, 600 gal.	744·0	204·0	210·0	288·0	1,800,900
Calf (birth value)	7·4	6·3	1·1	—	16,358
Total	751·4	210·3	211·1	288·0	1,817,258

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	9·6	17·1	20·0	4·8

[1] This covers residual milk production to a total of 600 gallons and 30 days' pregnancy allowance.

TABLE V.—DAIRY COW.

WHOLE YEAR: SPRING CALVING: MINISTRY STANDARDS.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Grass (good), 91 days [1]	2338·7	482·3	81·9	1155·7	1992·9	1719·9
,, (poor), 61 ,, [2]	952·8	83·4	7·1	500·2	619·3	543·1
Winter ration.						
Maintenance, 213 days	2918·1	157·6	34·1	1384·5	1661·4	1256·7
Production, 236 gal. milk	678·7	141·0	33·6	371·8	625·6	578·4
Pregnancy allowance, 91 days	123·8	25·5	4·6	61·0	105·6	91·0
Total	7012·1	889·8	161·3	3473·2	5004·8	4189·1
	Calories, 9,308,928. Non-protein digestible nutrients, lb., 3844·2.					
PRODUCTS.	As for Autumn Calving.					

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	10·7	19·5	23·6	5·5

[1] This covers 4 gallons of milk daily.
[2] Taken as supplying a maintenance ration.

TABLE VI.—DAIRY COW.

WHOLE LIFE: BASED ON AVERAGE OF SPRING AND AUTUMN CALVING.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Birth to first calf	11,491·0	1106·1	267·3	6448·0	8414·5	6955·9
3 Complete years	22,205·4	2912·6	542·7	11,063·6	16,096·4	13,570·8
	33,696·4	4018·7	810·0	17,511·6	24,510·9	20,526·7
Less 1 pregnancy allowance	123·8	25·5	4·6	61·0	105·6	91·0
Total	33,572·6	3993·2	805·4	17,450·6	24,405·3	20,435·7
	Calories, 45,393,858. Non-protein digestible nutrients, lb., 19,303·0.					

PRODUCTS.	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Milk, 1800 gal.	2232·0	612·0	630·0	864·0	5,402,700
Calves (3), 240 lb.	22·2	18·9	3·3	—	49,074
* Cow beef, incl. edible offal	251·3	90·1	160·6	0·6	846,113
Carcase 653 lb. *Total*	2505·5	721·0	793·9	864·6	6,297,887

	D.M.	Energy.	Prot.	Fat
EFFICIENCY PER CENT.				
Total	7·5	13·0	18·1	4·1

K·O = 5·3%. Cow as Wood Newman 3 yr old Shire No 1.

TABLE VII.

DAIRY COW.

MØLLGAARD'S RATION FOR 1100 LB. COW GIVING "20 MILK UNITS," I.E. 20,000 CALS.[1] IN MILK.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Maintenance.						
6·6 lb. oats	5·7	0·50	0·26	3·1	4·4	3·9
7·0 lb. barley straw	6·0	0·05	0·04	2·9	3·0	1·6
Maintenance	11·7	0·55	0·30	6·0	7·4	5·5
Production.						
51·5 lb. swedes	5·9	0·36	—	4·3	4·7	3·8
1·76 ,, soyabean meal	1·6	0·67	0·02	0·5	1·4	1·1
3·19 ,, rapeseed cake	2·9	0·86	0·24	0·7	2·3	1·9
2·42 ,, peas	2·1	0·44	0·02	1·3	1·9	1·7
3·30 ,, palm kernel cake	2·9	0·56	0·17	1·5	2·6	2·4
5·06 ,, coconut cake	4·5	0·83	0·39	2·1	4·1	3·9
Production	19·9	3·72	0·84	10·4	17·0	14·8
Total	31·6	4·27	1·14	16·4	24·4	20·3

	Total.	Production.
Calories	45,384	31,620
Non-protein digestible nutrients	19·02	12·33

Cals. from protein : 22·0 per cent.

PRODUCTS.	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Milk, 6·128 gal.	7·60	2·08	2·14	2·94	18,394

EFFICIENCY PER CENT.	D.M.	Energy.	Prot.	Fat.
Total	24·1	40·5	48·7	11·3
Partial	38·2	58·2	55·9	17·4

[1] Heat of combustion value.

TABLE VIII.—DAIRY COW.

MØLLGAARD AND MINISTRY STANDARDS FOR 1 YEAR; 11 CWT. COW, 600 GAL. MILK + CALF, COMPARED

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
MØLLGAARD.						
Maintenance, 365 days	4562·5	215·4	116·8	2336·0	2883·5	2153·5
Milk, 600 gal.	1948·4	364·2	82·2	1018·3	1664·5	1449·1
Pregnancy allowance	136·3	25·5	5·8	71·2	116·5	101·4
Production	2084·7	389·7	88·0	1089·5	1781·0	1550·5
Total	6647·2	605·1	204·8	3425·5	4664·5	3704·0

	Total.	Production.
Calories	8,675,970	3,312,660
Non-protein digestible nutrients, lb.	3896·5	1292·0

PRODUCTS.	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Milk, 600 gal.	744·0	204·0	210·0	288·0	1,800,900
Calf	7·4	6·3	1·1	—	16,358
Total	751·4	210·3	211·1	288·0	1,817,258

EFFICIENCY PER CENT.	D.M.	Energy.	Prot.	Fat.
Total	11·3	20·9	34·8	5·4
Partial	36·0	54·9	54·0	16·3

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
MINISTRY.						
Maintenance, 365 days	5000·5	270·10	58·40	2372·5	2847·0	2153·5
Milk, 600 gal.	1725·0	358·50	85·50	945·0	1590·0	1470·0
Pregnancy allowance	123·8	25·48	4·55	61·0	105·6	91·0
Production	1848·8	383·98	90·05	1006·0	1695·6	1561·0
Total	6849·3	654·08	148·45	3378·5	4542·6	3714·5

	Total.	Production.
Calories	8,449,236	3,153,816
Non-protein digestible nutrients, lb.	3720	1213

PRODUCTS. As above.

EFFICIENCY PER CENT.	D.M.	Energy.	Prot.	Fat.
Total	10·8	21·5	32·2	5·7
Partial	40·6	57·6	54·8	17·4

1. *Comparison of Standards.*—The detailed comparison presented of English and Danish standards shows that there is no significant difference between the two. The data for American cows give energetic efficiencies practically identical with the English and Danish. Brody did not estimate the efficiency of protein conversion but the American standard for protein is so close to the English that there could be no significant difference in efficiency of protein conversion between American and English practice. Metabolism data from the experiments of Ritzman and Benedict, in which no definite standards appear to have been used (the object of the studies was to compare the use of different feeds), when the results have been accurately corrected for gain or loss of body substance and taking into account the types of rations used, suggest no criticism of the standards. And indeed, the standards themselves are based on similar studies. When, therefore, it is suggested, on the basis of short-term group-feeding tests with rations below the usual standards in energy or protein, that these standards are too high, there are two reasons for caution in accepting these conclusions. First, in the absence of control metabolism experiments, it cannot with certainty be assumed that losses of body substance have not occurred and, second, although, over a short period of time such losses might be insignificant, continued loss over one or several

TABLE IX.

MILK PRODUCTION: TOTAL AND PARTIAL EFFICIENCY.

TWO STANDARDS COMPARED: 11 CWT. COW: WINTER RATION.

Milk yield.	TOTAL EFFICIENCY: PER CENT.							
	Ministry of Agriculture.				Møllgaard (Danish standard).			
	D.M.	Energy.	Prot.	Fat.	D.M.	Energy.	Prot.	Fat.
6 gal. daily	24·0	40·9	47·0	11·4	23·3	39·5	48·2	10·9
4 ,, ,,	19·7	35·1	43·5	9·7	19·4	34·0	45·0	9·2
2 ,, ,,	12·7	24·6	35·1	6·5	13·1	24·1	37·8	6·3
600 gal. in a year	11·1	21·8	32·5	5·8	11·4	21·3	35·2	5·5
	PARTIAL EFFICIENCY: PER CENT.							
	43·1	60·9	56·9	18·4	38·2	58·2	56·0	17·4

lactations might seriously affect the health of the cow and its milking capacity or fertility. This view has been stressed by Møllgaard and by Ritzman and Benedict (pp. 158-159). Indeed, Møllgaard, discussing earlier low protein experiments, shows that although partial efficiencies of over 90 per cent. can be procured, they cannot be maintained over any long period of time. He considers that a partial efficiency of 70 per cent. is the maximum which can be attained without danger to the health of the cow. It should be noted that a partial efficiency of 70 per cent. would be attained with Møllgaard's ration by reducing the proportion of energy supplied as protein to about 18 per cent. Further, in certain experiments, as a result of which it has been suggested that the Ministry protein standards for milk production are too high, the rations appear to provide a proportion of energy from protein which is within the range of 15 to 25 per cent. given by Møllgaard as that within which protein intake may be varied, in short period experiments, without affecting milk yield. For instance, such calculations as are possible from Mackintosh's (1939) experiments indicate that the lower protein supply still represented over 15 per cent. of the energy of the ration and no effect on milk yield would be expected. In practice, economy could, of course, be obtained by feeding at the lower limit of 15 per cent. but there is no certainty that, at this level, the health and productivity of the cows would be maintained over long periods.

Such small differences as do exist between standards for milk production appear, therefore, to have little practical significance. They may, it is true, give rise to apparent differences in efficiency between cows of different breeds or localities but these are small and, in comparison, for instance, with the difference in efficiency between milk production and meat production, they are negligible.

2. *Species Comparisons.*—The efficiency of milk production by the ewe, producing 3 gallons weekly (Table X), is comparable with that of a cow giving 3 gallons daily when measured on the energy basis and higher, on the protein basis, than that of the 6 gallon cow on standard winter ration. The protein of the ewe's ration studied is relatively low, supplying only 16·6 per cent. of the energy. The ewe may, therefore, be more justly compared with the cows in the experiment of Morris and Wright (1934) where the apparent

TABLE X.

EWE: MILK PRODUCTION.

MINISTRY RATION FOR 3 GAL. MILK PER WEEK.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Medium meadow hay, 12 lb.	10·3	0·55	0·12	4·88	5·86	4·44
Thou. head kale, 140 lb. .	22·1	2·03	0·24	13·02	16·10	14·42
Decort. cottonseed meal, 1·75 lb.	1·6	0·64	0·13	0·34	1·45	1·23
Flaked maize, 1·75 lb. . .	1·6	0·16	0·04	1·24	1·53	1·47
Crushed barley, 3·5 „ . .	3·0	0·26	0·04	2·22	2·64	2·50
Total	38·6	3·64	0·57	21·70	27·58	24·06

Calories, 51,299. Non-protein digestible nutrients, lb., 23·0.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Milk, 3 gal. . . .	5·79	1·83	2·22	1·44	15,446

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	15·0	30·1	50·3	9·7

efficiency of protein conversion (not corrected for change in body substance) was 45·6 per cent. and the percentage of the energy of the ration from protein was 14·4 per cent. Taking this into account and making allowance for the possibly large error in the assumptions made regarding both yield and composition of ewe's milk, it may be said that there is no evidence of any difference between the potential efficiencies of the cow and ewe.

This is in agreement with Brody's conclusion from comparison of the cow, goat and rat, and this conclusion is further supported by Mitchell and Kelley's (1938) estimates of the energetic efficiency of milk production in the sow. It may at least be said that there does not appear to be any significant species difference in the efficiency of milk production.

3. *Energetic Efficiency.*—In terms of the total digestible energy of the ration, the feeding standards themselves, applied to winter feeding in which the supply of nutrients can be accurately adjusted, show energetic efficiencies of 24·6 per cent. for an 11 cwt. cow and a yield

TABLE XI.—MILK PRODUCTION: ENERGETIC EFFICIENCY (*Data from Literature*).

Author and Date.	No. of Cows.	Breed.	Milk Yield (F.C.M.) and Period.	Efficiency per cent.	Notes.
Eckles, 1913	10	Jersey, Holstein, Ayrshire, Shorthorn	10·46 to 34·26 lb. daily, eight for one year: two for 120 days	12·7 to 19·7	Calculated by Armsby and Moulton in terms of gross energy.
				19·8 to 33·3 (21·3 to 35·8)[1]	Calculated by Brody in terms of digestible energy.
Forbes and Voris, 1932	9	Holstein, Friesian	11,783 lb. in lactation of 313 days.[2]	20·96	For lactation period: in terms of gross energy.
				18·68	For whole year: in terms of gross energy.
Brody and Proctor, 1935	67	Jersey		29·6 (31·9)	Mathematical analysis of feed consumption and production records from literature (including those of Eckles above).
	146	Holstein		27·8 (29·9)	
	243	Jersey, Holstein and Guernsey	28·26 lb. daily	28·3 (30·4)	
	243	Jersey, Holstein and Guernsey	,,	28·7 (30·9)	Corrected for changes in bodyweight.
			Superior	32·5 to 41·8 (35 to 45)	Same data: cows classified according to milk yield.
			Good	23·2 to 32·5 (25 to 35)	
			Inferior	13·9 to 23·2 (15 to 25)	
Brody and Cunningham, 1936	5	Brown Swiss	41·49 lb. average daily for 120 days	26·0 (28·0)	Mathematical analysis of records.
	28	Shorthorn	32·56 lb. ,, ,, ,, ,,	27·5 (29·6)	Exhibition cows.
	25	Jersey	45·59 lb. ,, ,, ,, ,,	31·2 (33·6)	
	15	Holstein	48·81 lb. ,, ,, ,, ,,	31·9 (34·3)	
	73	Above four groups together	40·97 lb. ,, ,, ,, ,,	29·6 (31·8)	
	45		46·21 lb. ,, ,, ,, ,,	30·9 (33·2)	Cows from same groups entered in "production classes." "Butter Test."
	65		41·93 lb. ,, ,, ,, ,,	30·0 (32·3)	"Economic Milk Production."
	34		35·69 lb. ,, ,, ,, ,,	27·5 (29·6)	"Milk and Beef."
	42	Superior Holstein	51·15 lb. average daily	31·9 (34·3)	Illinois Testing Plant.
	10	Holstein	36·20 lb. ,, ,, for 224 days	32·0 (34·4)	Pennsylvania Nutrition Institute data.
	368	All Brody data together	33·04 lb. ,, ,,	28·8 (31·0)	
	1	Jersey	25,946 lb. in one year	44·1 (47·5)	Champion cow: computed efficiency.
	1	Holstein	30,476 lb. ,, ,,	40·4 (43·5)	,, ,, ,, ,,
Edwards, 1936					Cows on test, London Dairy Shows, 1922-1934. Efficiency calculated by method of Brody and Ragsdale.
	741	Cows (all breeds)		37·0 (39·8)	Milked thrice daily.
	750	,, (,,)		34·7 (37·3)	,, twice ,,
	390	Heifers (all breeds)		34·3 (36·9)	Milked thrice daily.
	432	,, (,,)		31·9 (34·3)	,, twice ,,
	36	Dairy Shorthorn	35 lb. daily	30·2 (32·5)	
	30	,, ,,	75 lb. ,,	38·6 (41·5)	
		Ayrshire	45 lb. ,,	35·3 (38·0)	
		,,	85 lb. ,,	41·2 (44·3)	
		British Friesian	45 lb. ,,	32·1 (34·5)	
		,, ,,	95 lb. ,,	41·4 (44·5)	
	466	Jersey	35·8 lb. ,,	36·1 (38·8)	First month after calving.
	467	,,	17·0 lb. ,,	27·2 (29·3)	Eleventh month after calving.
Axelsson, 1940		Swedish	< 6600 lb. in one year	29·2	Calculated from data for 880 Recorded Herds, 1934-1935, classified in groups. Limits only shown here.
			> 12,000 ,, ,,	38·0	

[1] All figures in brackets refer to Brody's original data or calculations by his methods; the others are recomputed to the energy value of 324 Cals. per lb. F.C.M. and 1860 Cals. per lb. T.D.N.

[2] Not F.C.M. Same data as Pennsylvania Nutrition Institute below.

of 2 gallons ; 35·1 per cent. for 4 gallons and 40·9 per cent. for 6 gallons daily. Estimates of efficiency by mathematical analysis of herd records are practically identical. Calculated from Brody's equation : feed consumption in lb. T.D.N. = 0·305 lb. F.C.M. + 0·053 $M^{0.73}$ (in lb.) + 2·1ΔM, the efficiency of an 11 cwt. cow giving 2, 4 or 6 gallons daily and assuming constant bodyweight, is, on our energy basis, 21·4 per cent., 31·1 per cent., or 37·6 per cent., which is only slightly below the Ministry standard. The efficiency of Swedish recorded herds, calculated from Axelsson's (1940, *b*) data, appears to be slightly above the Ministry standard. The accurate metabolism studies of Ritzman and Benedict and the group-feeding tests show no significant deviation. The differences between these several results and the values derived from the standards are well within the range of ± 15 per cent. of the mean percentage efficiencies, as was tentatively predicted on page 9.

That is to say, cows rationed in accordance with feeding standards do, in practice, on the average, give the expected results, and cows in special feeding tests give milk yields which could have been predicted from the rations fed.

The energetic efficiency of the grazing cow, as calculated from the Ministry indications regarding consumption, is less than that of the stall-fed cow. The amount of grass that will be eaten in one day is estimated to supply enough starch equivalent to produce only 4 gallons

Table XII.

DATA OF RITZMAN AND BENEDICT.

Corrected for Changes in Body Energy and Protein.

Daily Yield of Milk lb.	Calories from Protein per cent.	Energy Efficiency per cent.	Protein Efficiency per cent.
30·1	19·0	26·5	26·7
27·9	21·5	23·7	27·0
26·2	8·8	24·4	40·1
25·8	19·2	27·2	29·0
25·3	16·3	23·8	29·0
23·9	16·4	19·6	36·1
20·9	18·0	19·9	30·9
17·7	11·3	17·9	47·1

of milk, but enough protein to produce 8 gallons. With this surplus of protein, which implies an increased loss of energy in urine and might be expected to give a higher loss of energy in the form of heat (thermogenic action), a slightly lower efficiency of energy conversion might be expected. But, since the difference is within the range of the possible error of ± 15 per cent. of the mean, it is impossible to be sure that the difference is significant or to attribute it to the high protein intake.

When, however, the efficiency with which the production ration is used is considered, the agreement between Brody's mathematical results and ours is not so good. An estimate based on the Ministry standards gives a partial efficiency of the order of 60 per cent. Brody and Procter's (1935) estimate from the equation fitted to the first series of records gave an efficiency of 61 per cent., later recomputed (Brody and Cunningham, 1936) to 62 per cent. On our energy basis this becomes approximately 57 per cent. But analysis of a second series of records separately gave partial efficiencies for different groups varying from 43 to 82 and an average for both series of 54 per cent. on Brody's energy values, or, corrected to our basis, 40 to 76 (average 50) per cent. This average differs so much from the estimate of 60 per cent. deduced from feeding standards, and the range of variation is so wide, that the material used by Brody has been examined to see whether an explanation could be found. Brody himself points out that the possible errors in his computations are many. There are

possibilities of inaccuracy of records; of faulty correction for liveweight changes and of incorrect partition of total energy between maintenance and production. The estimate of production energy will be affected by all the errors present. In the second series of records used, one set, according to Brody's statement, refers to cows of various breeds at a " Purchase Exposition " where the cows appear to have been fed *ad lib.* but, as far as possible, without feed being rejected; another refers to cows at a Testing Plant where the object was to secure maximum possible milk yield and feed was therefore probably not strictly rationed. Both sets would be expected to give relatively uneconomical results and they do. This leaves, in the second series, only the experiment station cows, with an efficiency, on Brody's basis, of 64 per cent., where errors in records may be confidently excluded, but, as described in the original publication (Forbes, 1935), the conditions of the experiment, which was concerned

TABLE XIII.

MILK PRODUCTION.

DATA FROM LITERATURE.

Author and Date.	Yield.	Total Efficiency per cent.				Cals. from Protein per cent.	Notes.
		D.M.	Energy.	Protein.	Fat.		
Ruston and Crawford, 1921	2·44 gal. daily	8·8	18·9	46·9	4·5	10·1	Farm practice (calculated from original data).
Morris and Wright, 1934	3·5 ,, ,,	16·2	27·1	45·6	6·9	14·4	Total efficiency (calculated from original data).
		33·6	47·7	57·5	13·0		Partial efficiency (calculated from original data). Comparison of protein for milk production. Period 1 : decorticated earthnut cake.
Watson and Ferguson, 1936	3·6 ,, ,,	14·8	28·5	42·4	7·5	18·0	Dried grass experiment. Period 1. Group A (calculated from original data). No difference recorded between different experimental groups.
Graves *et al.*, 1940	2·48 ,, ,,	9·8	23·2	22·3	6·6	24·4	Fed alfalfa hay only.
	3·31 ,, ,,	12·3	26·6	29·2	7·4	21·7	Fed alfalfa hay and ground barley.
	2·78 ,, ,,	10·6	24·3	33·1	6·4	17·6	Fed alfalfa hay and corn silage.

with mineral metabolism, were such as to suggest that the health and performance of the cows was not normal. It has not been possible to examine all the data used in the first series, but the experiments of Harrison and Savage (1932, 1933), of Perkins (1925) and of Hills (1922) were all concerned with the comparison of different levels of protein in the ration, and both Perkins and Hills, at least, supplied in their rations an amount of energy which exceeded that of standards now accepted as adequate. For instance, the ration used by Perkins supplied about 50 per cent. more energy than Armsby's standard and Armsby's standard is 10 per cent. above Mollgaard's (see Kriss, 1931). Unless, therefore, the surplus energy was converted into increase in bodyweight, and adequate correction made, the tendency would be for estimates of both total and partial energetic efficiencies to be low. But the calculation of total efficiency from Brody's equation fitted to the first series shows no significant difference from ours. It must, therefore, be concluded that the low estimate of partial

efficiency in the second series is due to failure to partition correctly the total digestible energy over the different purposes for which it was used. Taking all these difficulties into account, there does not appear to be any adequate evidence to invalidate the estimate of 60 per cent. partial efficiency as attainable by cows rationed on feeding standards now accepted as adequate.

4. *Efficiency of Protein Conversion.*—For the 11 cwt. cow and yields of 2, 4 and 6 gallons of milk, the efficiencies with which the protein equivalent of the winter ration, representing 21 per cent. of the energy, is converted to milk protein are 35·1, 43·5 and 47·0 per cent. That is to say, efficiency increases rapidly with milk yield (Fig. 2). But the grazing cow, yielding 4 gallons of milk and deriving 32 per cent. of its energy from protein, shows a conversion efficiency of only 25·7 per cent., which is far below that of the stall-fed cow giving the same yield. It has already been pointed out that the protein supply, when the sole feed is pasture (fresh or as hay) is in excess of the requirements. In Ritzman and Benedict's metabolism experiments with alfalfa hay alone the protein conversion efficiencies were only 29·0 and 26·7 per cent. Four of the experiments with hay, silage and grain, in which the protein intake was high, gave efficiencies of from 27·0 to 36·1 per cent., efficiency and intake varying inversely. But the experiment with soya bean hay and the last experiment with hay, silage and grain, in both of which the protein intake was low, gave efficiencies of 40·1 and 47·1 per cent. The group-feeding tests of Graves *et al.* (1940) in Table XIII also showed a very low efficiency, 22·3 per cent., for cows fed on alfalfa hay only, and an increase when the protein was reduced by addition of grain or silage. The other group-feeding tests, in which the level of protein feeding was low or very low, showed very high protein efficiencies. The data of Ruston and Crawford (1921), Morris and Wright (1934), Watson, S. J. and Ferguson (1936) and Graves *et al.* (1940) did not permit of correction for losses or gains of body protein and the efficiencies may be overestimated in the low protein experiments where, for instance, in Watson and Ferguson's test all but one of the cows lost weight, and underestimated in the alfalfa hay tests where most of the cows gained in weight. But those of Ritzman and Benedict have been accurately corrected. When, therefore, these efficiencies are compared with the corresponding milk yields on the one hand and the percentage of the energy of the diet derived from protein on the other, it will be seen that, although efficiency increases rapidly with milk yield, this increase may be entirely masked by the effect of the level of dietary protein.

The partial efficiency of conversion of protein in standard winter rations is of the order of 56 per cent. For the grazing cow it is less. The low protein experimental rations just discussed would give very high partial efficiencies. These and other similar experiments have been used as evidence that the standard allowances of protein are too high, but it has been suggested above (under 1. *Comparison of Standards*) that the argument is not necessarily sound.

The data may, therefore, on the whole, be taken to indicate that the standards are reliable; that the protein intake should not exceed in energy value 25 per cent. of the total Calories and that, below this level, the efficiency increases as milk yield rises and as intake falls, the figure in any given experiment depending on the balance between intake and yield. There is no clear indication that the standards are too high. But there is clear evidence that the feeding of cows on good quality pasture alone, or on legume hay, is highly uneconomical of protein. This appears to justify the practice advocated by Hansson (1922) in Sweden of feeding a supplement of low protein grain to grazing cows.

5. *Milk Yield.*—The effect of the level of production on the efficiency of conversion holds for different milk yields whether they represent different stages in one lactation or the lactation averages of cows of different productive capacities. The flush of lactation is the time of highest efficiency. During this period the "average" cow may temporarily attain an efficiency comparable with the lactation average of the show cow as computed by Brody and by Edwards (1936) from Brody and Ragsdale's nomogram (1935). At the

height of lactation a champion cow probably produces with an energetic efficiency of about 50 per cent.

The relationship between daily milk yield and total energetic efficiency (see Fig. 1) may be summarised approximately as follows :—

Daily yield in gallons . .	1·5	2	2·8	4	6	9	15
Energetic efficiency, per cent.	20	25	30	35	40	45	50

From these facts it is apparent that, in the process of herd improvement, the most rapid increase in efficiency will be got by elimination of the poorest cow. An increase in average yield from 1·5 gallons to 3 gallons daily would give more than a 50 per cent. increase in efficiency while an increase from 3 gallons to 6 gallons would give an increase of less than a third and from 6 gallons to championship level an increase of less than a fourth. Further, in the individual case, it is most important to ensure that rationing is adequate to permit of the maximum possible yield when the yield is highest, *i.e.* at the flush of lactation. It will be more profitable to be sure of the highest possible yield then, than to expend feed on trying to prolong lactation or materially reduce the rate of decline. These deductions are confirmed by the experimental work of Bonnier (1935) and Bonnier and Bäckström (1935) who showed that milk production, although it will take place at the expense of body substance, may easily be inhibited by poor rations but not increased by feeding above accepted standards.

Milk yield increases with bodyweight of the cow. Much attention has been devoted to the analysis of data with a view to determining whether the large or the small cow is the more economical producer. From his studies of herd records and from his comparison of milk production in the cow, goat (Brody, Sandberg and Asdell, 1938) and rat (Brody and Nisbet, 1938), Brody concludes that the energetic efficiency of milk production is independent of bodyweight. Where a correlation appears to exist, he considers it to be the result of the system of rationing used. For instance, if the maintenance ration be increased in proportion to bodyweight, then, if the light cow is correctly rationed, the heavy cow will be overfed and will appear less efficient. Gaines, from the analysis of numerous herd records, has reached the same conclusion with regard to cows within one breed, but states that it is not always true when different breeds are compared. In his latest analysis (Gaines, Rhode and Cash, 1940) Jerseys were more efficient than Holsteins. It is not possible to say whether, or to what extent, this and other differences pointed out by Gaines (1938-1940) may be due to differences in feeding standards. For example, in a comparison of American and Danish records (1938), the equations which fit the two sets of data differ in such a way that American cows appear the more efficient at high levels and Danish cows at low levels of production. This could most simply be explained on the basis that the American cows had a relatively higher maintenance and lower production ration, and, from a comparison of American and Scandinavian standards (*cf.* Table I), it is likely that this was so.

It seems probably therefore that, if cows were accurately rationed in accordance with standards based on physiological principles, the efficiency of milk production would be found to be independent of bodyweight. It would then follow that the best "index of merit" for dairy cows would, as Gaines *et al.* suggest, be the ratio of weight of milk produced to bodyweight.

6. *Allowance for Pregnancy and Calf.*—When the feed cost of milk production is increased by a standard allowance for pregnancy and the birth value (as food) of the calf is added to that of the milk produced, the efficiency of the cow is reduced, but only by a small amount. There is again no significant difference between the effect of the Ministry and the Danish pregnancy allowances.

TABLE XIV.

EGG PRODUCTION.

MINISTRY STANDARDS AND ALL-MASH RATION: MEDIUM HEAVY BIRD.

1 Egg Daily.

	D.M.–gm.	P.E.–gm.	Fat–gm.	CHO–gm.	G.D.E.–gm.	S.E.–gm.
FEED CONSUMPTION.	124·6	17·1	5·9	73·5	108·7	97·1
	Calories, 446.		Non-protein digestible nutrients, gm. 87·1.			
	D.M.–gm.	Prot.–gm.	Fat–gm.	Total Cals.		
PRODUCTS. 1 egg	12·5	6·8	5·5	79·0		
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT. *Total*	10·0	17·7	39·7	6·3		
Partial (approximate)	25·5	45·2	68·0	16·1		

200 Eggs in 1 Year.

	D.M.–gm.	P.E.–gm.	Fat–gm.	CHO–gm.	G.D.E.–gm.	S.E.–gm.
FEED CONSUMPTION.	37,438·1	5150·4	1774·5	22,073·3	32,633·9	29,171·5
	Calories, 133,799.		Non-protein digestible nutrients, gm. 26,155.			
	D.M.–gm.	Prot.–gm.	Fat–gm.	Total Cals.		
PRODUCTS. 200 eggs	2500	1360	1100	15,800		
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT. *Total*	6·7	11·8	26·4	4·2		

120 Eggs in 1 Year.

	D.M.–gm.	P.E.–gm.	Fat–gm.	CHO–gm.	G.D.E.–gm.	S.E.–gm.
FEED CONSUMPTION.	33,536·9	4613·7	1589·6	19,773·2	29,233·3	26,131·5
	Calories, 119,857.		Non-protein digestible nutrients, gm. 23,429.			
	D.M.–gm.	Prot.–gm.	Fat–gm.	Total Cals.		
PRODUCTS. 120 eggs	1500	816	660	9480		
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT. *Total*	4·5	7·9	17·7	2·8		

Egg Production.

Energy Conversion.—The total efficiency of energy conversion, calculated from the Ministry standards (1939) and rations (1936) for egg yields of 120 or 200 yearly and 1 egg daily (Table XIV), is 7·9, 11·8 or 17·7 per cent. for " medium heavy birds " of average weight 5·5 lb. The light bird, of average weight 4 lb., assuming the weight of an egg to be the same,

Table XV.

EFFICIENCY OF PRODUCTION OF EGGS.

Data from Literature.

Author and Date.	Yield or Liveweight.	Total Efficiency : per cent. D.M.	Energy.	Protein.	Fat.	Notes.
Brody, Funk and Kempster, 1938	Leghorns (4 lb.) 100 eggs yearly		9·7 (11·0)			Mathematical treatment of original data on feed consumption and egg production over three years.
	" " 150 "		12·3 (14·0)			
	" " 200 "		14·9 (17·0)			
	" " 250 "		17·6 (20·0)			
	" " 360 "		23·7 (27·0)			First series.
	New Hampshire Reds (5 to 5·5 lb.) 121 to 200 eggs per annum		7·6 to 12·1 (8·7 to 13·8)			Second series.
Byerly, Titus and Ellis, 1933	145·8 eggs per annum to 204·5 eggs per annum		8·1 to 11·8 (9·2 to 13·4)			Range, as calculated by Brody *et al.*
Alder, 1934	207·9 eggs in one year		14·9 (17·0)			Av. efficiency for year by Brody *et al.*
Waite, 1934	Leghorns (about 3·75 lb.) 117·7 to 255·8 eggs in one year		9·8 to 16·6 (11·2 to 18·9)			Range by Brody *et al.*
	Rhode Island Reds 121·4 to 237·6 eggs in one year		8·8 to 14·0 (10·0 to 16·0)			" " "
	Barred Plymouth Rocks 148·4 to 232·8 eggs in one year		10·3 to 14·2 (11·7 to 16·2)			" " "
Bird and Sinclair, 1939	Barred Plymouth Rock pullets (6·3 to 7·2 lb.)					
	Approximate rate of laying : eggs per annum — 82	2·8	5·1 (5·8)	10·5	1·9	December : data for two weeks.
	294	9·2	10·5 (18·8)	34·0	6·3	April : " "
	257	8·2	14·7 (16·8)	30·4	5·6	May : " "
	217	7·4	13·3 (15·2)	27·6	5·1	July : " "
	175	6·0	10·7 (12·2)	22·1	4·1	August : " "
Bennett, 1939	Leghorn × R.I.R. pullets (5 lb. 6 oz.) 201·6 eggs in 336 days	7·0	12·6	26·8	4·6	Battery production. (Calculated from original data.)
	Leghorn × R.I.R. pullets (5 lb.) 196·1 eggs in 336 days	7·2	13·0	27·6	4·7	Intensive production. (Calculated from original data.)

produces slightly more efficiently because of its lower maintenance requirement. The efficiencies are 9·0 for 120 eggs ; 13·3 for 200 and 19·6 for 365 eggs yearly (Fig. 5).

For comparison, the calculations of Brody, Funk and Kempster (1938) from their own and other experimental data, and computations from the data of Bird and Sinclair (1939) and Bennett (1939) are given in Table XV. Brody, and Bird and Sinclair use as their basis the heat of combustion of the egg. The data have been recomputed to our basis and the

original values are given in brackets. The first series of Brody's data gave higher efficiencies than do any of the other calculations, but Brody's second series gave lower efficiencies than the first. Allowing for the fact that some of the results (*e.g.* Bennett's) are for intensive egg production, and others from egg-laying contests, the results as a whole are in excellent agreement and confirm the validity of the standards.

The Ministry standards and rations give a partial energetic efficiency for egg production of the order of 45 per cent. From his first set of data, Brody, using a mathematical equation similar to that for milk production, calculated the partial efficiency to be 68 (77 per cent. on his energy basis) but states that, taking account of the nature of the data and of the computations, the difference between that value and the 57 (60) per cent. estimated for milk production cannot be regarded as significant. Recalculated on a different basis, however, he found for egg production a partial efficiency of only 47 (54) per cent., and he compares this with the efficiency of his second milk series and again concludes that the partial efficiency of egg production is of the same order as that of milk production. Since, however, it has already been shown that the data of the second milk series are likely to have given low results ; in view of the difficulty of accurately partitioning total energy by mathematical treatment using unconfirmed assumptions, and since his second estimate for eggs, on a simple basis of feed consumption, agrees with ours, it may be tentatively concluded that the estimate of 45 per cent. partial efficiency will not be greatly in error. This shows the hen to be only three-quarters as efficient as the cow in converting the energy of the production ration.

Protein.—The efficiency with which total protein is converted is more than twice as high as the efficiency of total energy conversion at each level of production (Fig. 6) and the partial efficiency of protein utilisation is 50 per cent. above the partial efficiency for energy.

Effect of Yield and Bodyweight.—It is obvious that total efficiency increases rapidly with the rate of egg laying, and that the light bird, assuming that the same number of eggs, of equal weight, are laid, produces more efficiently than the heavy bird. Brody, from his analysis of the data collected by him, states that the weight of an egg increases with the weight of the bird, when different breeds are compared, at a rate proportional to the 0·73 power of bodyweight. That is, it increases at the same rate as maintenance requirement and since it is the difference in maintenance requirement which would cause a difference in efficiency of egg production, it appears as if heavy breeds should, on the average, produce as efficiently as light breeds. On the other hand, within the same breed, he says egg weight increases with only the 0·15 power of bodyweight. In this case the lighter bird must be the more efficient unless, in practice, the heavier bird tends to lay more eggs than the light.

Brody also deduces from his data that each breed has an optimum bodyweight, about 4 lb. for Leghorns and 5·75 lb. for Rhode Island Reds and Barred Plymouth Rocks, at which egg production in numbers is maximal.

Restricted Feeding.—Heywang (1940) has made a study of the effect of restricted feeding on egg production in Leghorn pullets. Control groups were fed *ad lib.* and experimental groups at levels of 87·5 and 75 per cent. of the feed consumption of the controls.

Reduction of feed intake to 87·5 per cent. reduced in the same proportion the total weight of egg produced during the 17 weeks which covered the peak of production ; loss of bodyweight was greater than in the controls. Over the whole year, egg weight production was reduced to 67·5 per cent. of that of the birds fed *ad lib.* Net gain of bodyweight was approximately the same in both groups.

Reduction of feed intake to 75 per cent. of the *ad lib.* consumption reduced egg weight production to 64·4 per cent. over the peak 17 weeks and to 46·4 per cent. over the whole year. Loss of bodyweight during the 17 weeks was greater and net gain over the year was less than in the controls.

Although accurate computation of efficiency is not possible from the data there is no evidence of a gain in efficiency by restricting the feed intake to 87·5 per cent. of that consumed

by the unrestricted birds, and the indication is that efficiency would have been much reduced when feed was restricted to 75 per cent.

Meat Production.

Beef.

The Ministry of Agriculture (1939) gives a detailed table of requirements for beef production in terms of S.E. and protein but suggests rations only for the fattening period. Using

Table XVI.

BEEF PRODUCTION.

Beef, Fattening Period Only: 9 to 10·7 Cwt. Liveweight.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
Ration.						
2 lb. maize germ meal	1·78	0·21	0·23	0·99	1·78	1·69
2 lb. decort. ground nut cake	1·79	0·83	0·14	0·40	1·75	1·46
6 lb. barley straw	5·16	0·03	0·03	2·45	2·58	1·38
100 lb. mangolds	13·20	0·40	—	9·70	10·20	6·80
Total daily	21·9	1·47	0·4	13·5	16·3	11·3
Feed Consumption.						
(112 days)	2452·8	164·6	44·8	1512·0	1825·6	1265·6

Calories, 3,395,616. Non-protein digestible nutrients, lb., 1615.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Products.					
Carcase (1200 lb. l.w.)	314·5	86·9	227·6	—	1,121,651
,, (1000 ,,)	193·9	69·6	124·3	—	653,753
Carcase gain	120·6	17·3	103·3	—	467,898
Edible offal (1200 lb. l.w.)	56·8	12·9	43·3	0·6	207,749
,, ,, (1000 ,,)	37·9	10·6	26·8	0·5	133,688
Edible offal gain	18·9	2·3	16·5	0·1	74,061
Total gain	139·5	19·6	119·8	0·1	541,959

	D.M.	Energy.	Prot.	Fat.
Efficiency per cent.				
Total	5·7	16·0	11·9	7·4

these suggestions calculations of efficiency during the fattening period have been made. In addition an account of the whole life history of beef cattle, under different systems of feeding and fattening, was constructed from experimental data supplied by Mr. A. Crichton.

Energetic efficiency during the fattening period only (Tables XVI to XVIII) is of the order of 16 per cent. for both the stall-fattened and grass-fattened bullock. Protein efficiency in stall fattening is of the order of 10 or 11 per cent. but only half as much when the bullock is grass fattened. The reason for the low protein efficiency of grass feeding is the same as operates in milk production. The protein supply is greatly in excess of the requirements.

TABLE XVII.

BEEF PRODUCTION.

BEEF, FATTENING PERIOD ONLY: 10·7 TO 12·5 CWT. LIVEWEIGHT.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION. (132 days)	2890·8	194·0	52·8	1782·0	2151·6	1491·6
	Calories, 4,001,976. Non-protein digestible nutrients, lb., 1903.					
	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.	
PRODUCTS.						
Carcase (1400 lb. l.w.) (1496lb) .	375·5	99·5	276·6	—	1,349,238	
„ (1200 „) (1285 lb)	233·0	84·3	148·7	—	784,015	
Carcase gain	142·5	15·2	127·3	—	565,223	
Edible offal (1400 lb. l.w.) .	67·9	15·1	52·1	0·7	249,146	
„ „ (1200 „) .	45·6	12·8	32·2	0·6	160,744	
Edible offal gain	22·3	2·3	19·9	0·1	88,402	
Total gain	164·8	17·5	147·2	0·1	653,625	
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT. *Total*	5·7	16·3	9·0	7·7		

TABLE XVIII.

BEEF PRODUCTION.

FATTENING PERIOD ONLY: ON GRASS. 8·5 TO 10·7 CWT. LIVEWEIGHT.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION. 110 lb. grass daily for 153 days	3366·0	412·4	84·2	1901·8	2591·8	2255·2
	Calories, 4,820,748. Non-protein digestible nutrients, lb., 2095·5.					
	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.	
PRODUCTS. 756 lb						
Carcase (including edible offal)	371·3	99·8	270·9	0·6	1,329,400	
Initial value (including edible offal) 500 lb . .	179·2	78·8	100·4	0·5	570,985	
Total gain	192·1	21·0	170·5	0·1	758,415	
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT. *Total*	5·7	15·7	5·1	8·1		

Over the whole period from birth to slaughter (Tables XIX to XXII) baby beef production gives a somewhat higher energetic and a very materially greater protein efficiency than does fattening at higher liveweights. The higher protein efficiency in the young animal is due to the relatively higher proportion of protein in the edible meat gains than in the mature animal, where the liveweight increase is chiefly fat. The higher efficiency of energy conversion is accounted for by the short life period and the lower proportion of total feed used for maintenance. The level of energetic efficiency attained in any given case will depend on

TABLE XIX.

BEEF PRODUCTION.

BABY BEEF: BIRTH TO 7 CWT. LIVEWEIGHT.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Milk, 450 gal.	576·0	144·0	175·5	216·0	801·0	769·5
Grass, 224 lb.	44·8	5·5	1·1	25·3	34·5	30·0
Maize, 525 ,,	456·8	40·2	14·2	338·6	423·2	407·4
Barley, 525 ,,	446·8	38·3	6·3	332·9	395·3	374·9
Bran, 1050 ,,	913·5	104·0	27·3	415·8	619·5	447·3
Silage, 700 ,,	191·1	8·1	6·3	93·1	126·7	89·6
Straw, 728 ,,	626·1	6·6	4·4	274·5	291·2	145·6
Roots, 3160 ,,	363·4	22·1	—	262·3	290·7	230·7
Hay, 930 ,,	797·0	27·4	4·7	324·6	369·2	204·6
Total	4415·5	396·2	239·8	2283·1	3351·3	2699·6

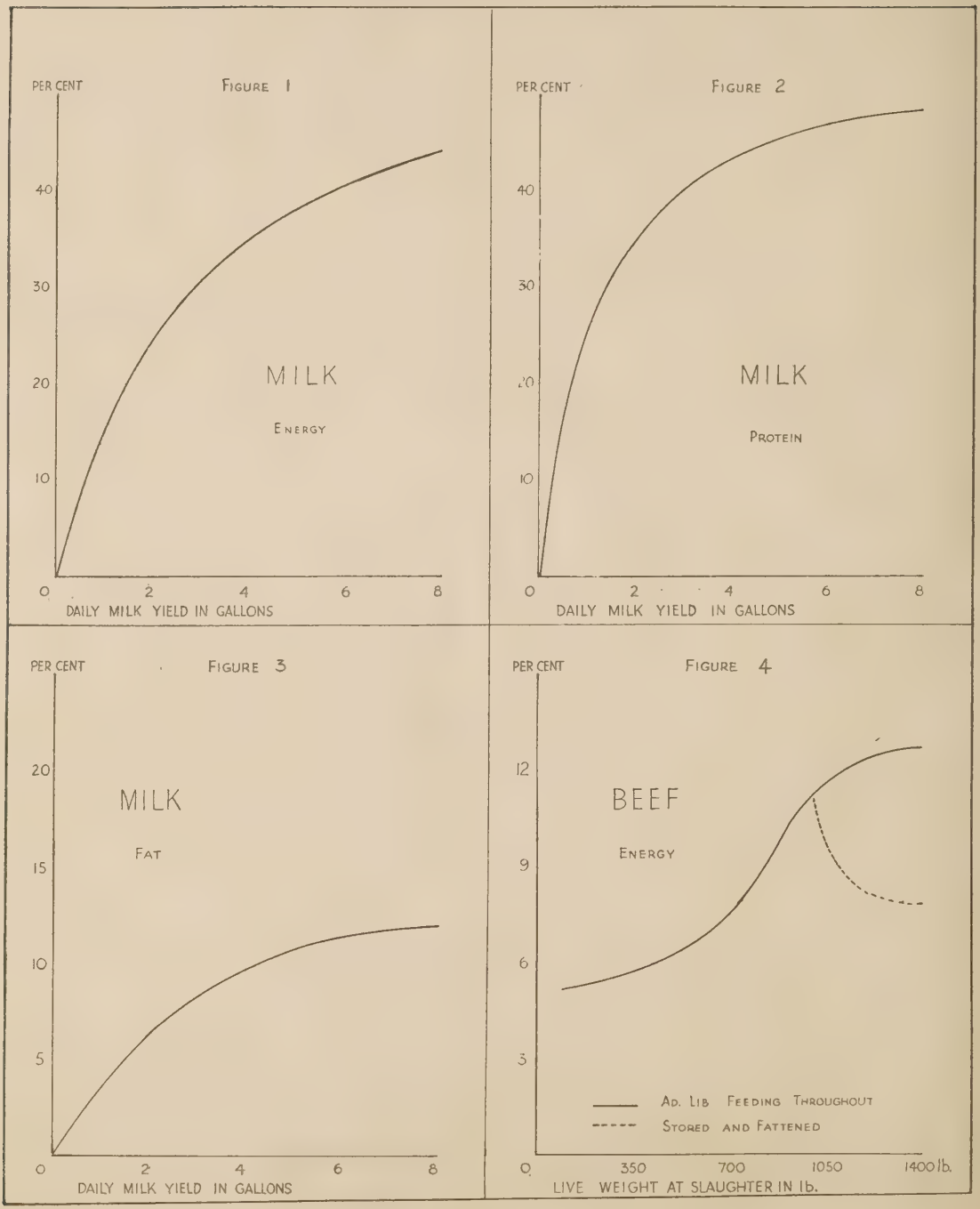
Calories, 6,233,418. Non-protein digestible nutrients, lb., 2835.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Carcase (478·5 lb.)	138·1	59·3	78·8	—	442,676
Edible offal	30·9	8·3	22·1	0·4	109,400
	169·0	67·6	100·9	0·4	552,076
Less birth value	7·4	6·3	1·1	—	16,358
Net gain	161·6	61·3	99·8	0·4	535,718

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	3·7	8·6	15·5	3·5

two main factors: first, the ease with which fattening can be induced and, second, the total time between birth and slaughter. In the young growing animal part of the feed supplied will necessarily be used for production of bone and other inedible tissues; in the fully grown animal as much as 90 per cent. of the liveweight increase is edible material and much of it fat. The more rapidly the animal is brought to slaughter weight, the less are the overhead costs of maintenance and the greater is the efficiency of feed conversion. This is well illustrated by the Missouri data on full-fed, medium-fed and scant-fed cattle, quoted by Armsby and Moulton (see below, p. 52). The practice of "storing" cattle must reduce the efficiency of feed conversion. On the other hand, it has been thought that liveweight gains become

ESTIMATED EFFICIENCIES.



ESTIMATED EFFICIENCIES.

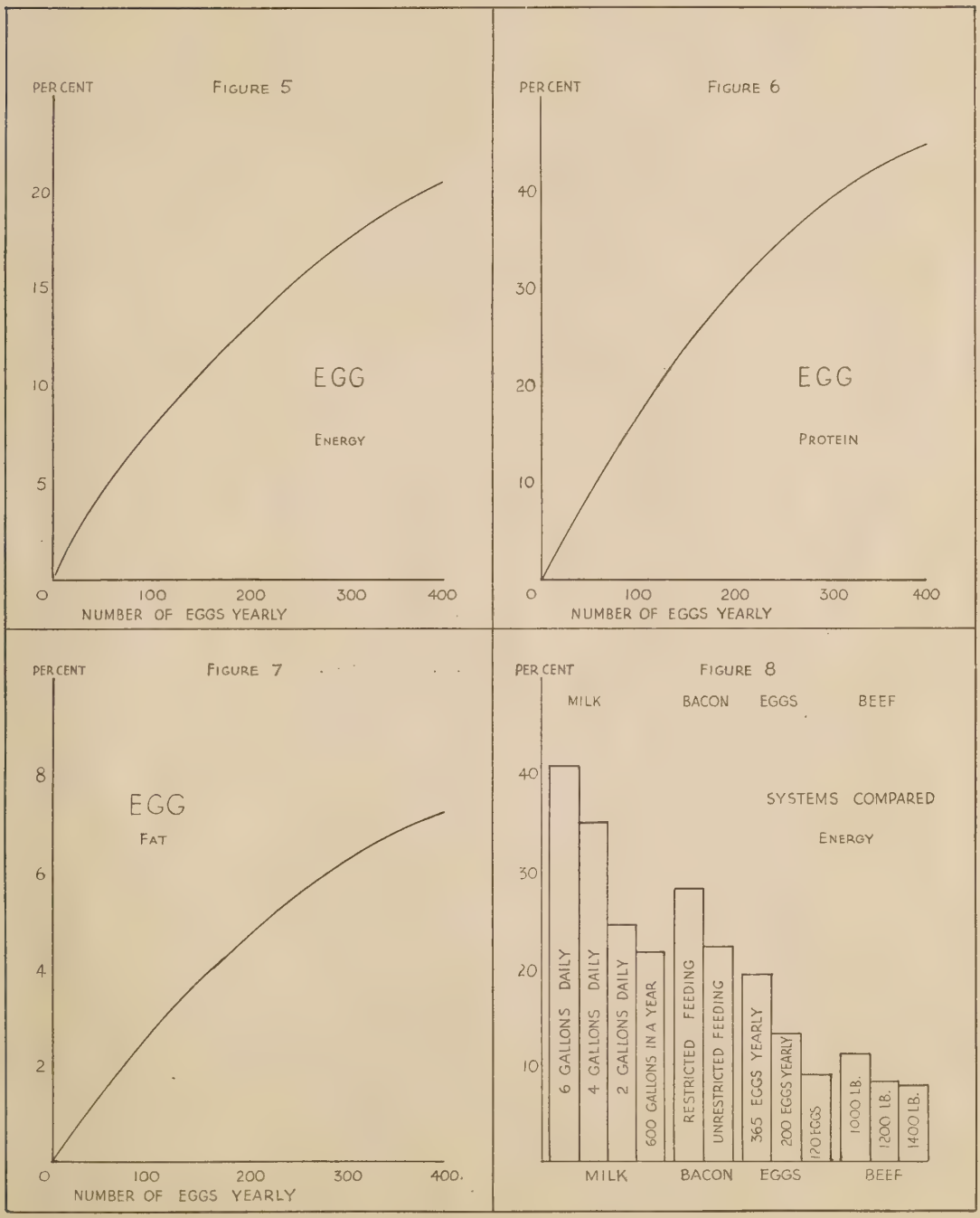


TABLE XX.

BEEF PRODUCTION.

BABY BEEF: BIRTH TO 9 CWT. LIVEWEIGHT.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Milk, 450 gal.	576·0	144·0	175·5	216·0	801·0	769·5
Grass, 224 lb.	44·8	5·5	1·1	25·3	34·5	30·0
Swedes, 5460 ,,	627·9	38·2	—	453·2	502·3	398·6
Hay, 910 ,,	779·9	41·9	9·1	370·4	444·1	336·7
Grass, 15,555 ,,	3111·0	381·1	77·8	1757·7	2395·5	2084·4
Oats, 240 ,,	208·1	18·2	9·6	113·8	158·6	142·8
Maize, 240 ,,	208·8	18·4	6·5	154·8	193·4	186·2
Undecort. cotton cake, 480 ,,	421·9	83·0	22·1	106·6	261·1	199·7
Turnips, 7294 ,,	620·0	29·2	—	401·2	437·6	320·9
Straw, 840 ,,	722·4	7·6	5·0	316·7	336·0	168·0
Total	7320·8	767·1	306·7	3915·7	5564·1	4636·8

Calories, 10,349,226. Non-protein digestible nutrients, lb., 4621.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Carcase (678 lb.) . .	278·5	80·4	198·2	—	985,552
Edible offal	48·7	10·8	37·4	0·5	178,771
	327·2	91·2	235·6	0·5	1,164,323
Less birth value . . .	7·4	6·3	1·1	—	16,358
Net gain	319·8	84·9	234·5	0·5	1,147,965

	D.M.	Energy.	Prot.	Fat.
EFFICIENPY PER CENT.				
Total	4·4	11·1	11·1	5·1

The composition of the carcase of this animal was taken as the average of Wood and Newman's fat bullocks, about 2 years old. For a liveweight at slaughter of 9 cwt. the carcase weight of these would give a very high killing-out percentage. But (*a*) the efficiency deduced is below that of Haecker's steers of the same liveweight and (*b*) reduction of the killing-out percentage to 62, which is exceeded by 22 months' old beef animals (Mackenzie, 1910) and by 900 lb. Hereford steers (Hankins and Titus, 1939), and reduction of the products in proportion, would reduce the energetic efficiency by less than 1 per cent. (11·1 to 10·3) and would not affect the argument.

Table XXI.—BEEF PRODUCTION.

Beef, Grass Fattened: Birth to 10·7 Cwt. Liveweight.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
Feed Consumption.						
Milk, 450 gal.	576·0	144·0	175·5	216·0	801·0	769·5
Grass, 224 lb.	44·8	5·5	1·1	25·3	34·5	30·0
Oats, 424 ,,	367·6	32·2	17·0	201·0	280·3	252·3
Roots, 28,408 ,,	2414·7	113·6	—	1562·4	1704·5	1250·0
Straw, 2968 ,,	2552·5	26·7	17·8	1118·9	1187·2	593·6
Grass, 29,835 ,,	5967·0	731·0	149·2	3371·4	4594·6	3997·9
Total	11,922·6	1053·0	360·6	6495·0	8602·1	6893·3

Calories, 15,999,906. Non-protein digestible nutrients, lb., 7324.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Products.					
Carcase (757 lb.)	314·5	86·9	227·6	—	1,121,651
Edible offal	56·8	12·9	43·3	0·6	207,749
	371·3	99·8	270·9	0·6	1,329,400
Less birth value	7·4	6·3	1·1	—	16,358
Net gain	363·9	93·5	269·8	0·6	1,313,042

	D.M.	Energy.	Prot.	Fat.
Efficiency per cent.				
Total	3·1	8·2	8·9	3·7

Table XXII.—BEEF PRODUCTION.

Beef, Stall Fattened: Birth to 12·5 Cwt. Liveweight.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
Feed Consumption.						
To 2½ years	11,922·6	1053·0	360·6	6495·0	8602·1	6893·3
Fattened 132 days	2,890·8	194·0	52·8	1782·0	2151·6	1491·6
Total	14,813·4	1247·0	413·4	8277·0	10,753·7	8384·9

Calories, 20,001,882. Non-protein digestible nutrients, lb., 9228.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
Products.					
Carcase (846 lb.)	375·5	99·5	276·0	—	1,349,238
Edible offal	67·9	15·1	52·1	0·7	249,146
	443·4	114·6	328·1	0·7	1,598,384
Less birth value	7·4	6·3	1·1	—	16,358
Net gain	436·0	108·3	327·0	0·7	1,582,026

	D.M.	Energy.	Prot.	Fat.
Efficiency per cent.				
Total	2·9	7·9	8·7	3·5

more expensive the heavier the animal becomes. From all these considerations the existence of an optimum slaughter weight or age at which the efficiency of beef production would be maximal seems likely.

The four illustrative computations made from Mr. Crichton's data suggest an optimum weight of about 9 cwt. and an age of just under 2 years. This view is not supported by calculations from the classical comparative slaughter experiment of Haecker. Data are given for feed consumption and carcase composition of calves of 100 lb. liveweight and subsequently at each 100 lb. up to 1500. Calculations have been made from the data for steers of approximately 200, 800, 1000, 1200 and 1400 lb. (Table XXIII) for comparison with the results of the practical experiments quoted above. Haecker's data cover the period from about

TABLE XXIII.

EFFICIENCY OF BEEF PRODUCTION.

HAECKER'S DATA.

	D.M.–lb.	C.P.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	N.P.D.N.–lb.	Calories.
FEED CONSUMPTION.							
200 lb. steer .	305·5	51·2	15·7	158·5	245·0	195	455,756
800 ,, . .	4767·1	477·0	135·4	2411·9	3193·5	2723	5,939,910
1000 ,, . .	6643·8	621·2	180·4	3472·4	4499·6	3887	8,369,163
1200 ,, . .	9506·8	899·8	267·5	5016·5	6518·2	5632	12,123,945
1400 ,, . .	10,091·4	864·0	295·1	5600·2	7128·1	6279	13,258,080

	D.M.–lb.	Prot.–lb.	Fat–lb.	Total Cals.
PRODUCTS.				
200 lb. steer .	19·9	15·3	3·9	44,908
800 ,, . .	164·7	72·4	88·7	508,801
1000 ,, . .	298·3	87·8	206·1	1,032,638
1200 ,, . .	426·5	105·9	315·7	1,528,597
1400 ,, . .	483·4	129·3	348·1	1,708,784
[Initial value .	9·7	7·9	1·3	20,177]

	D.M.	Energy.	Protein.	Fat.
EFFICIENCY PER CENT.				
200 lb. steer .	3·3	5·4	14·5	1·3
800 ,, . .	3·3	8·2	13·5	3·2
1000 ,, . .	4·3	12·1	12·9	5·3
1200 ,, . .	4·4	12·4	10·9	5·6
1400 ,, . .	4·7	12·7	14·0	5·5

weaning to slaughter but the cost from birth to weaning would not significantly affect the result. In Haecker's experiments the animals were intensively fed from weaning throughout life and the total consumption of concentrates was very high in comparison with what would be used in practice, even in stall fattening. His 1400 lb. steer was only 117 weeks old at slaughter as against 150 weeks for our 1400 lb. bullock. The steers comparable in liveweight with our bullocks show energy efficiencies of 8·2, 12·1, 12·4, and 12·7 per cent. That is to say at the slaughter weight of about 7 cwt. and an age of 83 weeks, Haecker's estimate of efficiency and ours are insignificantly different. At 9 cwt. and 88 weeks Haecker's steer was only slightly more efficient than our bullock but the effect of " storing " the older cattle is to reduce the efficiency by about a third. Taking all the calculations from Haecker's data together, it appears that energetic efficiency in the intensively fed bullock increases in an

S-shape curve (Fig. 4) from about 5 per cent. at 200 lb. to a maximum of about 12·7[1] per cent. at 1400 lb. slaughter weight. There is no indication of an optimum at a lower weight. The low efficiency of the stored bullock may, therefore, be attributed chiefly or entirely to the effect of storing. Baby beef appears to be produced with about maximal possible efficiency but the efficiency of the mature bullock, under ordinary practical conditions, is not likely to be more than two-thirds of the maximum. This does not exclude

TABLE XXIV.

FAT LAMB REPRODUCTION.

MINISTRY RATION: LAMB FATTENED FROM 70 LB. TO 100 LB.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Marrowstem kale, 90 lb.	12·60	1·26	0·27	6·93	9·36	8·19
Medium meadow hay, 4 ,,	3·43	0·18	0·04	1·63	1·95	1·48
Decort. ground nut cake, Crushed barley, Flaked maize, 2½ ,,	2·05	0·45	0·08	1·20	1·95	1·78
Total weekly:	18·08	1·89	0·39	9·76	13·26	11·45
Total for 12 weeks:	217·0	22·7	4·7	117·1	159·1	137·4

Calories, 295,926. Non-protein digestible nutrients, lb., 127·9.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Carcase	20·22	6·08	14·14	—	70,951
Edible offal	3·90	1·06	2·79	0·05	13,833
	24·12	7·14	16·93	0·05	84,784
Less: carcase + edible offal (70 lb. value)	10·41	4·15	6·22	0·03	34,011
Net gain	13·71	2·99	10·71	0·02	50,773

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	6·3	17·2	13·2	8·4

the possibility that there is an age or liveweight at which the efficiency of the fattening period alone is maximal.

In efficiency of protein conversion Haecker's steers are at a double advantage in their shorter life and a slightly lower average protein intake. These together explain that the partially grass fed and older bullock is again only two-thirds as efficient in protein conversion as the intensively fed and younger steer of the same slaughter weight.

Mutton and Lamb.

It has not been possible to make an extensive study of mutton and lamb production since so much of the life of the sheep is spent on pasture and it is impossible to estimate either the

[1] It is possible, in view of the experiments on restricted *versus* unrestricted feeding of pigs described below, that full feeding does not give maximum possible efficiency. But the position for pigs is still obscure and this question would require accurate *ad hoc* investigation.

TABLE XXV.—BACON PRODUCTION.

ROWETT INSTITUTE RATION: RESTRICTED AND UNRESTRICTED FEEDING COMPARED.

	Parts.	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
COMPOSITION OF RATION.							
Middlings	40	34·40	4·34	1·56	18·92	27·92	22·60
Barley	30	25·53	2·19	0·36	19·02	22·59	21·42
Flaked maize	10	8·90	0·92	0·20	7·09	8·73	8·40
Ground maize	10	8·70	0·76	0·27	6·45	8·06	7·76
White fish meal	10	8·70	5·30	0·33	0·12	7·40	5·89
	100	86·2	13·5	2·7	51·6	74·7	66·1

Restricted Pigs: Average of 32. Weaning to Bacon Weight, 220 lb.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Total feed per pigs: 609 lb.	525·0	82·2	16·4	314·2	454·9	402·5

Calories, 846,114. Non-protein digestible nutrients, lb., 351·9.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Carcase (incl. ed. offal)	75·8	16·3	59·3	0·2	280,818
Weaning value (incl. ed. offal)	12·2	3·8	8·4	—	42,499
Total gain	63·6	12·5	50·9	0·2	238,319

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	12·1	28·2	15·2	14·5

Unrestricted Pigs: Average of 32. Weaning to Bacon Weight, 220 lb.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Total feed per pig: 752 lb.	648·2	101·5	20·3	388·0	561·7	497·1

Calories, 1,044,762. Non-protein digestible nutrients, lb., 434·7.

	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.
PRODUCTS.					
Carcase (incl. ed. offal)	75·2	17·3	57·7	0·2	275,929
Weaning value (incl. ed. offal)	12·2	3·8	8·4	—	42,499
Total gain	63·0	13·5	49·3	0·2	233,430

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	9·7	22·3	13·3	11·3

consumption of grass or its feeding value. The efficiency of conversion during the fattening period of feeder lambs has been calculated for the Ministry ration (Table XXIV). Apart from a slightly higher efficiency of protein conversion there is little difference between the lamb and bullock.

TABLE XXVI.

PORK PRODUCTION.

ROWETT INSTITUTE RATION: RESTRICTED AND UNRESTRICTED FEEDING COMPARED.

Restricted Pigs: Average of 32. Weaning to 160 lb. Liveweight.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Total feed per pig: 355 lb.	306·0	47·9	9·6	183·2	265·2	234·7
	Calories, 493,272. Non-protein digestible nutrients, lb., 205·3.					
	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.	
PRODUCTS.						
Carcase (incl. ed. offal.)	49·4	12·9	36·4	0·1	177,859	
Weaning value (incl. ed. offal)	12·2	3·8	8·4	—	42,499	
Total gain	37·2	9·1	28·0	0·1	135,360	
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT.						
Total	12·2	27·4	19·0	13·6		

Unrestricted Pigs: Average of 32. Weaning to 160 lb. Liveweight.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Total feed per pig: 440 lb.	379·3	59·4	11·9	227·0	328·7	290·8
	Calories, 611,382. Non-protein digestible nutrients, lb., 254·4.					
PRODUCTS.	Taken as above.					
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT.						
Total	9·8	22·1	15·3	11·0		

Pork and Bacon.

The primary calculations (Tables XXV and XXVI) for both restricted and unrestricted feeding from weaning to slaughter show no significant difference between pork and bacon in the efficiency with which dry matter, energy and fat are produced. The efficiency of protein conversion is slightly higher for pork than for bacon. The period between 160 and

220 lb. liveweight, calculated by difference, shows practically the same efficiency as that of bacon production. This is a finding very different from what happens in beef production where the energetic efficiency increases with liveweight at slaughter in the intensively fed animal and the efficiency of the fattening period alone is considerably above that of the whole life. Since the pig is still actively growing at bacon weight and is, in no sense, a mature animal, differences of the same order as those found for beef animals would not be expected. But the absence of any difference suggests that the assumed value for the analysis of the pork pig may be too high (*cf.* p. 12). The error cannot, however, be large and is insignificant in view of other major considerations.

Restricted Feeding.—Under the conditions of the experiment, restricted feeding, with a meal consumption per head of 85 lb. less for pork and 143 lb. less for bacon, was in all respects considerably more efficient than unrestricted feeding.

TABLE XXVII.

EFFICIENCY OF MEAT PRODUCTION.

DATA FROM THE LITERATURE.

Author and Date.	Liveweight.	Total Efficiency: Per Cent.				Notes.
		D.M.	Energy.	Protein.	Fat.	
BEEF.						
Haecker, 1920 . .	103 lb. to 207 lb.	3·4	5·4	14·5	1·3	Stall-fed to appetite, 121 days } Illustrative examples.
	95 ,, 815 ,,	3·3	8·2	13·5	3·2	,, ,, ,, 581 ,, } Calculated from original data.
	101 ,, 1008 ,,	4·3	12·1	12·9	5·3	,, ,, ,, 616 ,,
	98 ,, 1204 ,,	4·4	12·4	10·9	5·6	,, ,, ,, 800 ,,
	105 ,, 1413 ,,	4·7	12·7	14·0	5·5	,, ,, ,, 819 ,,
PORK AND BACON.						
Woodman and Evans, 1939	46·15 lb. to 171·7 lb.	10·6	24·2	17·6	11·8	Meat meal experiment. (Calculated from original data.)
,, ,, ,,	46·15 ,, 200 ,,	11·7	27·7	15·8	13·8	Meat meal experiment. (Calculated from original data.)
,, ,, 1940	54·05 ,, 200 ,,	10·9	25·6	17·7	12·2	Protein minimum. (Calculated from original data.)
Jespersen and Olsen, 1939	To produce and wean litter of 7 pigs: average weight 33 lb.	5·2	11·2	10·3	5·3	This standard is calculated to maintain condition of sow through lactation.
TABLE POULTRY.						
Macdonald and Kay, 1937	Cockerels: fattening period, 3·73 lb. to 4·75 lb.	5·1	12·5	10·7	5·8	Fattened in 20 days on feed similar to Ministry ration.
Harshaw, 1938 . .	Fattening period, 4·3 lb. to 5·1 lb.	6·5	15·5	5·5	8·1	Fattened in 14 days on maize, oats and dried buttermilk.

Feeding experiments of Woodman and Evans (1939, 1940), when the same analytical values are assumed to be applicable to carcase composition, give results which are in close agreement with these and intermediate between restricted and unrestricted feeding (Table XXVII).

Other experiments in restricted feeding, in which the conclusions have been based on feed consumption per lb. liveweight increase, have not given uniform results. Mansfield *et al.* (1935, 1937) found that restricted feeding gave an economy of feed consumption, in spite of the longer time required to reach bacon weight, and a higher quality of carcase. Fishwick (1936) found no feed economy but the pigs on restricted feed had less back fat. McMeekan (1940, 1941) has made a detailed study of the differences in conformation and gross (fat and lean) composition of the carcase which may be induced by varying the level of feeding, the

change over from one level to the other being made at 16 weeks of age. His results may be summarised as follows :—

McMEEKAN'S DATA.

Age in Days, Feed Consumption and "Fat" in Carcase at 200 lb. Liveweight.

Plan of Feeding.	Average Age in Days.	"Meal Equivalent" per lb. Live-weight Increase.	Per cent. of Carcase Weight.	
			Muscle.	Fat.
High-high	165	5·05	40·0	38·5
High-low	211	4·28	44·2	34·3
Low-high	211	5·61	36·8	43·3
Low-low	325	5·17	49·1	27·7

Feed consumption to 200 lb. liveweight was least for pigs fed first at a high and later at a low level and greatest when the process was reversed. The difference in terms of "meal equivalent" per lb. liveweight increase was 30 per cent. of the low level. When feed was restricted throughout, consumption was about 2·4 per cent. above that when it was high throughout. But the differences in gross carcase composition, as shown by the percentages of "muscle" and "fat" suggest that grading by lb. meal per lb. liveweight increase may not accurately reflect the economy of feed conversion. For instance, the percentage of "fat" in the carcases of the low-high pigs was 26 per cent. above that in the high-low pigs, giving an excess nearly equal to the feed consumption excess, and the "fat" excess in the high-high was similar to the feed excess over the high-low pigs. It is much to be regretted that this extraordinarily interesting anatomical study should not have been completed by chemical analysis of the carcases.

It appears clear from these results that conclusions regarding economy of feed conversion based on liveweight increase may not be valid when the production of food, or the energy value of the edible product is considered. Indeed they are not necessarily valid when the energy value of liveweight increase is the basis of comparison. For, in the experiments of Burroughs and Carroll (1939), in which restricted pigs consumed 3·51 lb. feed per lb. liveweight increase and full-fed pigs only 3·39, the energy values of the liveweight increases were 2890 and 3290 Calories per kg. so that the energetic efficiency (in terms of metabolisable energy) of the restricted pigs was only 28·7 per cent. and that of the full fed 36·7 per cent.

Table Poultry.

Ministry rearing and fattening rations (1936) and information from the Poultry Department of the Duthie Stock Farm were used to compute the efficiency of production of spring chicken and fat cockerels. The energetic efficiency of chicken production is less and of fat cockerel production similar to that of prime beef production, but the efficiency of protein production is about twice as high (Table XXVIII).

From these two calculations the efficiency of the fattening period alone has been derived with the following results : dry matter 5·2, energy 12·4, protein 10·5 and fat 5·8 per cent. These values are practically identical with those computed for Macdonald and Kay's (1937) fattening experiment. Harshaw's (1938) data for slightly heavier birds give a higher energetic and fat and lower protein efficiency, as would be expected (Table XXVII). Taking these three sets of data together, there is no significant difference between the efficiencies of production of fat beef and fat table poultry.

TABLE XXVIII.

TABLE POULTRY.

SPRING CHICKEN: MINISTRY RATIONS.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
15 weeks { 4·4 lb. chick mash	3·74	0·65	0·26	1·98	3·36	2·94
15 weeks { 6·34 lb. growers' ,,	5·51	0·72	0·32	3·20	4·85	4·34
Total	9·25	1·37	0·58	5·18	8·21	7·28

Calories, 15,271. Non-protein digestible nutrients, lb., 6·51.

	D.M.–lb.	Prot.–lb.	Fat–lb.	Total Cals.
PRODUCTS.				
3·75 lb. liveweight . .	0·41	0·36	0·05	881

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	4·4	5·8	26·3	0·8

FAT COCKERELS: MINISTRY RATIONS.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
First 15 weeks . . .	9·25	1·37	0·58	5·18	8·21	7·28
Fattening 20 days . .	5·70	0·56	0·41	3·02	4·66	4·17
Total	14·95	1·93	0·99	8·20	12·87	11·45

Calories, 23,938. Non-protein digestible nutrients, lb., 10·48.

	D.M.–lb.	Prot.–lb.	Fat–lb.	Total Cals.
PRODUCTS.				
4·75 lb. liveweight . .	0·70	0·42	0·28	1962

	D.M.	Energy.	Prot.	Fat.
EFFICIENCY PER CENT.				
Total	4·7	8·2	21·8	2·7

Some of the important points emerging from the calculations of efficiency of milk production and discussed separately above have, in so far as is possible in regard to meat production, been dealt with in this general review. The following points require further consideration.

Optimum Protein for Meat Production. The Ministry standards for protein in the rations of beef cattle are not given in a form which lends itself to discussion except in so far as the

total protein intake decreases in proportion to the S.E. requirement steadily from 7 cwt. liveweight upwards. The proportion of the energy derived from protein in the fattening ration is 11·5 per cent. In view of Axelsson's (1940, *a*) suggestion, from the analysis of Breirem's data for pigs and Kellner's data for cattle, that there is an optimum protein level at which the utilisation of the energy is highest, and of other similar suggestions, to which reference was made earlier (p. 8), the experimental data used here have been examined in this light. The results are summarised below :—

PROTEIN IN RATIONS : PER CENT.

	Of Dry Matter.	Of Digestible Organic Matter.	Of Energy.
BEEF—			
Baby beef, 7 cwt.	8·9	13·6	15·4
,, ,, 9 ,,	10·5	15·4	16·9
Beef, grass fattened	8·8	13·3	14·9
,, stall ,,	8·4	12·5	14·2
Fattening period only	6·7	9·6	11·5
Haecker : 800 lb. steer	10·0	15·8	14·7
1000 ,,	9·4	14·5	13·6
1400 ,,	8·6	12·8	11·9
PIGS—			
Rowett Institute	15·7	19·9	22·6
Woodman and Evans—			
Standard : 1st ration	16·4	21·0	23·8
2nd ,,	15·0	18·9	21·7
3rd ,,	11·1	13·6	15·7
Protein minimum experiment :			
1st ration	12·6	16·0	18·5
2nd ,,	11·8	14·7	17·1
3rd ,,	10·3	12·6	14·7
McMeekan—			
High protein : 1st ration	31·2	39·8	42·1
2nd ,,	25·3	31·5	34·7
Low protein : 1st ,,	31·2	39·8	42·1
2nd ,,	11·0	12·8	14·8

From Axelsson's examination of Kellner's data, maximum efficiency in cattle fattening appears to occur when protein is between 15 and 18 per cent. of the digestible organic matter of the ration. Only two of the rations analysed by us, taken over the whole life period, reach this level ; the fattening period alone is well below it.

Again, Axelsson deduces from Breirem's data that maximum energetic efficiency is attained by pigs of about 100 lb. liveweight when protein supplies about 15 per cent. of the dry matter of the ration and that for smaller pigs the proportion should be higher ; for heavier pigs, lower. The Rowett Institute ration gives 15·7 per cent. of the dry matter as protein, uniformly over the whole period from weaning to bacon weight. Woodman and Evans and McMeekan graded their protein intake. The standard allowance in the experiments of Woodman and Evans gives, over the entire period from weaning to bacon weight, an amount slightly less than that allowed by the Rowett Research Institute. In an early experiment, Woodman *et al.* (1936), a higher protein allowance was tested and found to inhibit rather than to promote growth and (1937) to give no increase in nitrogen retention. Although the lower intake in the first protein minimum ration inhibited early growth, the efficiency of feed utilisation per lb. liveweight increase was not significantly affected. Nor did McMeekan find any obvious differences in the gross composition of the carcases between his high and low protein pigs. Axelsson's conclusions can, therefore, on these considerations, not be taken

as established. The data are not sufficient, however, to rule out the existence of a protein optimum for energy conversion in meat production. It still remains theoretically possible that such an optimum or an optimum range exists, and certainly differences in protein intake of the magnitude in McMeekan's experiments would make a significant difference to the efficiency of protein conversion. From a comparison of the figures for protein intake in terms of energy, it appears as if the optimum for the period of active growth might be of the same order as for milk production (15 to 25 per cent.) and, for the fattening period only, possibly of the same order as for maintenance (10 per cent.) or slightly more.

Validity of Standards.—It has already been stated that the form in which the Ministry standards are presented does not lend itself to discussion. To sum the requirements of an animal from birth to a given slaughter weight would require too many assumptions regarding rate of liveweight increase to make comparison with the practical experiments profitable. But, it may be noted that suggestions for new standards, in which maintenance requirements are expressed as lb. S.E. per 100 lb. liveweight (or on any other direct proportional basis) are, in any case, unreliable and undesirable since maintenance requirement does not increase in proportion to liveweight but at a rate less than this. Calculations of efficiency of production, based on rate of liveweight increase per lb. feed above maintenance, when maintenance requirement is estimated on a proportionate basis, will overestimate the efficiency at higher weights. The surplus over true maintenance requirements will be greater than that assumed.

On the basis of a stall-feeding experiment, Watson, J. A. S., Skilbeck and Ellis (1937) have criticised the Ministry standards for sheep and proposed new standards. With intakes of S.E. below those recommended by the Ministry for maintenance of the liveweight of the experimental animals they claim to have produced small liveweight increases. They present the following table, in which the figures have reference to 100 lb. initial liveweight, and " gross efficiency " is the ratio of lb. liveweight increase to lb. total S.E. :—

Starch Equivalent of Weekly Ration.	Ministry Standards.		New Standards.	
	" Expected " Liveweight Increase, lb. per week.	Gross Efficiency Ratio.	" Expected " Liveweight Increase, lb. per week.	Gross Efficiency Ratio.
10	0·50	1 : 20 *	1·57	1 : 6·4
11	1·00	1 : 11	1·80	1 : 6·1
12	1·50	1 : 8	2·03	1 : 5·9
13	2·00	1 : 6·5	2·26	1 : 5·8
14	2·50	1 : 5·6	2·49	1 : 5·6

* The original table erroneously gives this as 1 : 40.

In the Ministry standards maintenance requirement is taken as 9 lb. S.E. and each increment is therefore 1 lb. S.E. above maintenance, giving 0·5 lb. " expected " liveweight increase. In the proposed new standards, no maintenance requirement is stated. The following comment is appended to the table. " On the first showing a low level of nutrition is extremely uneconomical and a satisfactory gross efficiency can be attained only by intensive feeding. On the other, the level of nutrition is relatively unimportant." Since, however, feeding at (true) maintenance level, without liveweight increase, would give a " gross efficiency " of zero, the general truth of the statement which Watson rejects is obvious. Its truth has also been demonstrated in the Missouri cattle experiments to which reference was made above. Further, it will be seen from the table that, while the Ministry standard assumes a rate of liveweight increase of 0·5 lb. per lb. S.E. above maintenance, the new standard gives a corresponding liveweight increase of only 0·23 lb. From these figures (10 — 1·57 ÷ 0·23) the maintenance allowance may be deduced. The two standards then are in lb. S.E. weekly :—

	Maintenance.	*Per lb. live-weight increase.*
Ministry	9	2
New	3·2	4·35

But 3·2 lb. S.E. weekly represents only 3440 Calories or less than 500 Calories daily, and, according to Benedict (1938, p. 131), a sheep of 45 kg. (99 lb.) expends 35·5 Calories per kg. or 1598 Calories in 24 hours. This indicates a weekly requirement of more than three times the new estimate, supporting the Ministry's standard. Further, a standard of the order of 2 lb. S.E. per lb. liveweight increase does not appear to be in question in respect of other forms of meat production, where maintenance requirements are more firmly established. The suggested distribution of total S.E. between maintenance and production does not therefore appear likely to be correct and further examination of the experimental data seems to be required.

COMPARISON OF ANIMALS AND SYSTEMS.

Relative Efficiencies of Animals. (Fig. 8.)

To compare the efficiencies of the several animals or processes, comparable periods must be chosen. The efficiency of fattening the mature bullock or pig can best be compared with that of the cow during full lactation, while the efficiency of the bullock from birth to slaughter is, for baby beef, more comparable with a complete year in the life of the cow and for the two to three year old bullock, with the whole life of the cow. The pork and bacon pigs are at slight advantage as compared with the cattle since the feed expenditure recorded covers only the period from weaning to slaughter. But the expense of rearing from birth to weaning would make only an insignificant reduction in efficiency. Further, the data for restricted feeding are probably better than would be procured in general practice. The efficiency of egg production as recorded must be compared with that of milk production. If the cost of rearing the pullet and the value of the discarded hen as food were taken into account, the efficiency of the whole life of the hen would be reduced in much the same way as that of the milk cow when the cost of rearing the dairy heifer and the value of cow beef are included.

Taking all these points into consideration, it is evident (Table XXIX) that the cow producing 6 gallons of milk daily is more efficient in all respects than any of the other animals.[1] Even at the productive level of 4 gallons daily it is superior, except in fat production, where it is excelled by the pig. The hen laying an egg daily competes with it, or equals it in protein production.

Over a year, the average 600 gallon cow is excelled in fat production by the pig, but only good hens, laying as many as 200 eggs in the year, equal it in protein production.

For meat production the pig is more efficient in all respects than beef cattle. As judged from the fattening period only, there does not appear to be any significant difference between beef and mutton production. Poultry produce meat protein more efficiently than either cattle or pigs but fat much less economically.

Relative Efficiencies of Systems.

Spring and Autumn Calving.

When a cow calves in spring (Table V) the flush of early grazing coincides with the height of lactation and is comparatively well utilised. The cow that calves in autumn (Table

[1] The figure of 50 per cent. efficiency of protein conversion for the lactating ewe is open to doubt, *cf.* p. 20.

TABLE XXIX.

EFFICIENCY OF PRODUCTION: COMPARISON OF ANIMALS.

	Efficiency: per cent.			
	Dry matter.	Energy.	Protein.	Fat.
MILK.				
Winter feeding:				
6 gallons daily	24·0	40·9	47·0	11·4
4 ,, ,,	19·7	35·1	43·5	9·7
2 ,, ,,	12·7	24·6	35·1	6·5
Summer feeding: grazing only.				
4 gallons daily	19·3	29·5	25·7	9·5
Complete year:				
600 gallons milk } Spring calving	10·7	19·5	23·6	5·5
1 calf: birth value } Autumn ,,	9·6	17·1	20·0	4·8
Whole life:				
1800 gallons milk 3 calves: birth value Cow beef } Average of spring and autumn calving	7·5	13·9	18·1	4·1
EGGS.				
Medium light bird: average weight 4 lb.				
1 egg daily	11·1	19·6	43·6	7·0
200 eggs yearly	7·5	13·3	29·8	4·7
120 ,, ,,	5·1	9·0	20·2	3·2
Medium heavy bird: average weight 5·5 lb.				
1 egg daily	10·0	17·7	39·7	6·3
200 eggs yearly	6·7	11·8	26·4	4·2
120 ,, ,,	4·5	7·9	17·7	2·8
BEEF.				
Baby beef: birth to 7 cwt. liveweight	3·7	8·6	15·5	3·5
,, ,, 9 ,,	4·4	11·1	11·1	5·1
Fat bullock: birth to 10·7 cwt. liveweight (grass fattened)	3·1	8·2	8·9	3·7
Fat bullock: birth to 12·5 cwt. liveweight (stall fattened)	2·9	7·9	8·7	3·5
Fattening period only: winter feeding.				
9 cwt. to 10·7 cwt. liveweight	5·7	16·0	11·9	7·4
10·7 cwt. to 12·5 cwt. liveweight	5·7	16·3	9·0	7·7
Fattening period only: grass fattened.				
8·5 cwt. to 10·7 cwt. liveweight	5·7	15·7	5·1	8·1
LAMB.				
Feeder lamb: fattening period.				
70 to 100 lb. in 12 weeks	6·3	17·2	13·2	8·4
BACON AND PORK.				
Bacon:				
40 lb. to 220 lb. liveweight: restricted feeding	12·1	28·2	15·2	14·5
,, ,, ,, ,, ,, unrestricted feeding	9·7	22·3	13·3	11·3
Pork:				
40 lb. to 160 lb. liveweight: restricted feeding	12·2	27·4	19·0	13·6
,, ,, ,, ,, ,, unrestricted feeding	9·8	22·1	15·3	11·0
TABLE POULTRY.				
Spring chicken: 3·75 lb. at 15 weeks	4·4	5·8	26·3	0·8
Fat cockerels: 4·75 lb. at 18 weeks	4·7	8·2	21·8	2·7

IV) must have a winter ration adequate for the height of lactation, and when on grass in the spring, the milk yield is rapidly falling. Unless grazing is limited, which is not common practice, the total intake of both energy and protein for the year is slightly in excess of requirements for spring calving and greatly in excess for autumn calving. Hence, although the efficiency of winter feeding is higher than that of grazing for the same milk yield, the efficiency of the cow calving in spring is, for the whole year, about 14 per cent. higher for energy and fat conversion and nearly 20 per cent. higher for protein conversion than that of the cow that calves in autumn.

Dairy and Beef Herds.

This comparison (Table XXX) is based on the whole life history of the cow and the average of spring and autumn calving data. It has been assumed that each cow has produced 3 calves. The validity of this assumption is discussed in the Appendix. It is further assumed that, in the dairy herds, the calves are slaughtered for veal. The veal calves are entirely milk-fed (20 gallons milk) from 80 lb. birth weight to 100 lb. slaughter weight (Ministry of Agriculture, 1937). The beef calves are taken as suckled and consuming 450 gallons of whole milk each. If they were reared on skimmed milk and meals the efficiency of the system might be slightly increased since the milk-fat would be included in the human food produced. The cost of rearing the dairy heifer was estimated from data supplied by Mr. A. Crichton which were compared in detail with the recommendations of the Ministry of Agriculture (1937) and found to be in close agreement. The cow has been allowed three complete years between first calving and slaughter.

The efficiency of production of milk and veal is practically twice that of production of milk and beef except for fat, where the ratio of the efficiencies is 1·4 : 1, still in favour of milk.

Pig Production.

It has not been possible to estimate, for practice in the United Kingdom, the efficiency of production of bacon including the overhead charges of maintenance of the sow and of pregnancy and lactation. Since common practice is to feed the sow so that there is great loss of weight during lactation, it would be impossible, even with accurate data of feed consumption, to make a reliable assessment.

Standards have, however, been set up on the basis of practical experiments in Denmark, for the production of satisfactory litters and maintenance of the sow's weight during lactation. Using this basis (Jespersen and Olsen, 1939), the efficiency with which a litter of 7 pigs can be produced and brought to weaning weight has been calculated. Distribution of the cost of maintaining the breeding boar over the appropriate number of litters would not significantly affect the estimate of efficiency. The results are given in Table XXVII. From these data the cost of rearing the weanling pig from birth has been estimated and added to the cost of rearing the bacon and pork pigs. The change in efficiency is, in all respects, insignificant.

Poultry.

Since the cost of rearing a pullet and the value of the discarded hen as meat would reduce efficiency in much the same way as the cost of rearing the dairy heifer and the value of the cow as beef reduced the efficiency of milk production, the efficiency of an egg laying flock will show approximately the same ratio to that of a dairy herd as egg production does to milk production.

TABLE XXX.

COMPARISON OF SYSTEMS.

MILK AND VEAL.

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Cow, whole life [1] . . .	33,572·6	3993·2	805·4	17,450·6	24,405·3	20,435·7
	Calories, 45,393,858. Non-protein digestible nutrients, lb., 19,303·0.					
	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.	
PRODUCTS.						
Milk, 1740 gal. . . .	2157·6	591·6	609·0	835·2	5,222,610	
3 Calves, 300 lb. (including edible offal) . . .	27·7	23·7	4·0	—	60,954	
Cow beef (including edible offal)	251·3	90·1	160·6	0·6	846,113	
Total	2436·6	705·4	773·6	835·8	6,129,677	
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT.						
Total	7·3	13·5	17·7	4·0		

MILK AND BEEF: CALVES SUCKLED.[2]

	D.M.–lb.	P.E.–lb.	Fat–lb.	CHO–lb.	G.D.E.–lb.	S.E.–lb.
FEED CONSUMPTION.						
Cow, whole life . . .	33,572·6	3993·2	805·4	17,450·6	24,405·3	20,435·7
3 Fat bullocks [3] . . .	42,712·2	3309·0	713·7	24,183·0	29,858·1	22,846·2
Total	76,284·8	7302·2	1519·1	41,633·6	54,263·4	43,281·9
	Calories, 100,929,924. Non-protein digestible nutrients, lb., 45,127·5.					
	D.M.–lb.	Prot.–lb.	Fat–lb.	CHO–lb.	Total Cals.	
PRODUCTS.						
Milk, 450 gal. . . .	558·0	153·0	157·5	216·0	1,350,675	
Cow beef (including edible offal)	251·3	90·1	160·6	0·6	846,113	
3 Fat bullocks (including edible offal)	1330·2	343·8	984·3	2·1	4,795,151	
Total	2139·5	586·9	1302·4	218·7	6,991,939	
	D.M.	Energy.	Prot.	Fat.		
EFFICIENCY PER CENT.						
Total	2·8	6·9	8·0	2·9		

[1] See Table VI.

[2] It has been assumed that each calf consumes 450 gal. whole milk.

[3] See Table XXII, less milk (included in cost of feeding cow).

Total Stock Population.

Feedingstuffs Supply.—Two estimates of the total available feedingstuffs of the United Kingdom, one for 1935 and a revised calculation for 1934 to 1938, have been published by Wright (1938, 1940). His revised total compares with ours as follows :—

	Thousand tons.			
	Home Grown.		Imported.	
	S.E.	P.E.	S.E.	P.E.
Estimate (1938), Table XXXI	16,802	2750	6139	1091
Wright's revised estimate (1934-1938). .	16,693	2672	4911	1006

It will be seen that the differences between the totals, except for the S.E. of imports, are very small, although there are many differences in the details.

Requirements of Stock Population.—The estimate given in Table XXXIV is compared below with the revised estimate given by Wright for the years 1934-1938.

TOTAL REQUIREMENTS FOR ONE YEAR.

	Thousand tons.			
	From Table XXXIV.		Wright.	
	S.E.	P.E.	S.E.	P.E.
Dairy cattle	6189	957	5580	930
Beef cattle and sheep	10,973	1597	11,710	1650
Horses	2225	470	2260	325
Pigs	1613	331	2000	375
Poultry	1243	226	1652	285
Total	22,243	3581	23,202	3565

Again, in spite of differences in detail, the overall estimates are very close.

Efficiency of Stock Population.—The basis of estimation, as set out in the Appendix and Table XXXIV, takes into account the additional overhead charges for maintenance and growth of the breeding stock and the losses due to infertility and disease. Considering these charges and the relative numbers in the different classes of stock, the percentage efficiencies are of the order to be expected. A total return of approximately 9 per cent. of the digestible energy and 11 per cent. of the protein equivalent consumed may appear low but the change in quality from feed to product must not be forgotten. Much of the feed consumed by farm animals is not capable of direct use as human food. The conversion, even of those feeds which might be so used, yields food of greater palatability and of higher value, especially for growth. Fat is synthesised from non-fatty materials and the fat soluble vitamins A and D, not present as such in plant foods, are prepared and stored by all except the pig. The nutritional value of the protein is increased and in addition certain minerals are concentrated, especially in milk and eggs.

The estimates presented here apply to intensive animal husbandry. They assume the availability of whatever types of feed are desired; that the animals are of high productive capacity and that the problem is one of how to make the best use of feed. Conditions will be quite different under extensive systems of animal husbandry where the animals are of low productive capacity, the methods simple and based on the indigenous, uncultivated grazing. The problems are then of low carrying capacity, often complicated by soil deficiency, and adverse climatic conditions (Duckham, 1932).

It is of interest to note that, where wide ranges of natural pasture are available and truly extensive animal husbandry is practised, beef or mutton is the product. At the opposite extreme, where pressure of population on the land is high, where agriculture is most intensive and the maximum return from a given quantity of feed is required, animal husbandry is concentrated on the production of milk and veal and pig products. As the wealth of such densely populated countries increases, beef and mutton produced on the intensive system reappear. Poultry production occurs under all semi-intensive and intensive systems but itself becomes intensive only where wealth is considerable.

Comparison with Earlier Estimates.

The efficiency with which different farm animals convert feed to human food was computed by Jordan (1901) in terms of edible solids as a percentage of digestible organic matter in the ration. The more important of his figures are : cow, milk production, 18 per cent. ; hog, 15·6 per cent. ; steer, 2·8 per cent. ; and fowl, egg production, 5·1 per cent. Jordan's estimate for milk production is the same as ours, recalculated in terms of digestible organic matter in the feed, for a cow producing 600 gallons in a year and that for the hog is almost identical with ours (15·4 per cent.) for the bacon pig on restricted feed. On the other hand, an efficiency of 2·8 per cent. for the steer is only about two-thirds of our lowest estimate (4·4 per cent.) and still lower than one based on Haecker's data. Further, an efficiency of only 5·1 per cent. for egg production would correspond to a lower annual egg yield than our assumed average of 120 eggs, which gives an efficiency of 6·6 per cent., or, if the annual egg yield for which it was calculated was not less, the efficiency of egg production has been underestimated. Brody criticises Jordan's estimate and, on the basis of his own studies of energetic efficiency, suggests that the correct figure would be 3 or 4 times as high. This seems unlikely. Our estimate for light birds producing an egg a day, which gives maximum efficiency, in Jordan's terms is only 14·3 per cent. Hence, since Brody's ration differs little from ours in composition, his estimate of Jordan's error seems excessive. We have not been able to consult Jordan's original publication and so cannot say whether his low estimate is due to an assumed low average level of production or to some other circumstance.

Other earlier estimates are those of Cooper and Spillman (1917) and of Middleton (1923). These writers were concerned with the human food produced from an acre of land. Cooper and Spillman treated the problem by imagining the acre planted with crops in such proportions as to provide a balanced ration, or, possibly, with some of the crops exchanged in part for equivalent feed grown elsewhere ; and then estimated the amount of milk, eggs, or other food which would be produced from the crop yield. Middleton merely states the yield of milk, beef or other product from an acre of certain single crops, and it is therefore difficult to compare the two estimates. In terms of food calories per acre, Cooper and Spillman's estimates are as follows : milk, 711,750 ; pork, 672,945 ; mutton, 137,295 ; beef, 130,000 ; and eggs, 132,192. That is to say, pork is estimated to yield nine-tenths and mutton, beef and eggs only one-fifth of the food energy produced in milk from 1 acre of crops. It seems, however, that the food energy yield in beef and possibly mutton has been seriously underestimated. The food produce is given, in each case, first as lb. of liveweight increase. The quantities of dressed product are then taken as 78 per cent. of the liveweight increase for pork, 55 per cent. for mutton and 57 per cent. for beef and the Calorie values per lb. of dressed product as 2465, 1215 and 1040. But the percentage of liveweight increase which is edible is much higher than 57 per cent. in the mature or nearly mature beef animal. Haecker's data and those of Wood and Newman indicate values from 86 per cent. between liveweights of 800 and 1000 lb. to over 90 per cent. between 1000 and 1200 lb. Further, the energy value of a lb. of liveweight increase during the fattening period, using the same data, is between 2600 and 3000 Calories, or, per lb. of edible product, between 3000 and

3300 Calories. The values assigned to mutton are probably also underestimates. On the other hand, the energy value for pigs of 2465 Calories per lb. of dressed carcase or 1923 Calories per lb. of liveweight increase is in good agreement with the figures used in Tables XXV and XXVI. The estimate for pigs is, therefore, confirmed, but for beef and probably for mutton, the efficiency of the fattening period is seriously underestimated. Per acre of land, the yield of human food energy as beef produced in a steer, say between the liveweights of 800 and 1000 lb., fattening at the rate stated by Cooper and Spillman (2·5 lb. daily for 87·7 days) would be about four-fifths of the energy yield as milk at the low level of production (1·8 gallon daily for 119·2 days) postulated by them. To give the low ratio of egg energy to milk energy suggested production must be assumed to have been at the extremely low rate of about 75 eggs per annum.

Middleton comes to the general conclusion that, from an acre of pasture, or of a single crop such as mangolds, a cow will produce 50 per cent. more human food than will a bullock. In arriving at this conclusion he assigns to prime fat beef the energy value of 2300 Calories per lb. We have just seen that this is less than its usual value and, therefore, in relation to the rate of milk production assumed, the efficiency of beef production during the fattening period is underestimated.

Middleton sums up his findings by saying that a good cow or pig returns as human food 14 to 16 per cent. of the feed energy ; a bullock, fat at 3 years old, 5 to 6 per cent., or, fat at 2 years old, 8 to 9 per cent. and a sheep, 10 to 12 per cent. Assuming that the basic assumptions with regard to milk production are comparable, *i.e.* that the estimate applies to not less than a year in the cow's life and more probably to the whole life, these values for milk and beef are similar to ours. We have not been able to compute efficiency for the whole life of the sheep, but during the fattening period the sheep does not appear to be more efficient than the bullock.

Armsby and Moulton have also made estimates of efficiency. They devote most of their book to the presentation and discussion of the basic data and the nature of the assumptions to be made in computing efficiency. Discussing methods of investigation, they point out that, although liveweight increase may be an adequate measure of economic results, it is not an adequate measure of efficiency of food production since the composition of the liveweight gain varies with the age of the animal and the method of feeding. The comparative slaughter method is believed to have a high degree of reliability. Although, they say, it has one weak point in the possibility of error in selection of the check animals, this error does not appear to be significant since " The net energy of a ration is practically the same when measured by the comparative slaughter test and by the respiration calorimeter."

Armsby and Moulton's final estimates of the practical efficiency of farm animals are made in terms of gross (heat of combustion) energy of the feed, and, for meat production, gross energy of liveweight increase in the animal. This procedure is supported by the suggestions that (*a*) " lack of ability of the animal to metabolise all the energy furnished it (may) be properly considered as a charge against the animal," and (*b*) " It may be as much the fault of the consumer as of the beef animal that more of the product formed is not used as human food." The former argument would be valid only if, for purposes of comparison, the different farm animals were fed on the same or closely similar rations. But in practice, the capacities of the several animals to digest and utilise different feeds is roughly known and allowed for in the planning of rations. Pigs and poultry are usually fed high concentrate rations of low fibre content because they make poor use of fibrous foods. Hence, the expression of efficiency in terms of gross energy does not, in practice, take account of the inability of the pig or hen to metabolise energy presented in certain forms. The likelihood is rather that the scales are weighted against the ruminant because the ruminant might utilise a high concentrate ration more completely than its usual mixed diet. This view is supported by data given by Armsby and Moulton for the net energy values of different

rations for ruminants. The net energy value of concentrates, as a percentage of gross energy, is twice that of roughages and 40 per cent. higher than that of a mixed ration of hay and grain.

The second suggestion is also of very limited significance. In the young beef animal (100 lb. calf) it is true that the energy value of the portion conventionally considered edible is only about 50 per cent. of the energy value of the whole carcase, but in the mature and fat animal, it is over 82 per cent. of the whole carcase and, if the calculation be made on the basis of liveweight increase during fattening, over 90 per cent. Since bone, hide and gut account for most of the inedible material in the young animal and these can scarcely be added to the edible portion, there will not be much difference between estimates based on the conventionally edible and the actually edible material.

The following table summarises Armsby and Moulton's estimates. The gross energy values of the rations were recalculated by them from the original data by the use of a conventional value for the energy equivalent of the dry matter consumed.

ENERGY OF MILK OR LIVEWEIGHT INCREASE AS PERCENTAGE OF GROSS (HEAT OF COMBUSTION) ENERGY OF THE RATION.

(Recalculated by Armsby and Moulton.)

Beef Cattle :	Jordan's data	Two steers	4·7 and 5·4
	Missouri data *	Full fed	17·7 to 8·1
		Medium fed	10·9 to 4·0
		Scant fed	7·7 to 2·3
	Haecker's data		8·1 to 11·0
	Missouri data, fattening period only (2 steers)		10·2 and 14·9
Dairy Cow :	Eckles's data		12·7 to 19·7
Pigs :	Washburn and Jones' data		14·4 to 44·3
	Swanson's data		3·3 to 39·1

* In the first two series of animals, efficiency decreases as liveweight increases from less than 200 lb. to over 1200 lb. in the full fed and over 800 lb. in the medium fed. In the scant fed there is no definite correlation between efficiency and liveweight at slaughter, the maximum weight attained being 685 lb.

Estimates from the same data of Jordan and Haecker have already been discussed, and those from Haecker's and Eckles's data, in terms of digestible energy of the feed and the conventional food portion, are included in Tables XXIII and XI. When comparing the beef animal and the dairy cow Armsby and Moulton select the better of the two steers, giving an efficiency of 14·9 per cent. during the fattening period, and say that it is not very greatly below the average of the ten dairy cows, 16·9 per cent. They go on : " On the whole these figures do not support the belief that the dairy cow is a more efficient transformer of energy than the beef steer." Yet there is a difference of 13 per cent. between the selected steer, considered only during the fattening period, and the average of ten cows, eight of them over an entire year. If comparison had been made with the height of lactation, which is more nearly comparable with the fattening period, the difference in favour of the cow would have been greatly increased and, if the conclusions had been given a wider basis, they would probably have been different.

Of the two sets of data on pigs, the first refers to growth in very young pigs, fed chiefly on milk, and the second to a series of trials on maize with various supplements. The range of efficiencies is of interest as indicating the effect of the balance of the ration. The lowest efficiency is for maize with a mineral supplement, a very poor ration, and the highest for maize, casein and minerals. These results are of little practical significance.

These estimates are concerned with a comparison of animals as part of a system of food production. Estimates relating to individual productive processes have already been discussed under the separate headings. The review of the literature affords no evidence to throw doubt on the estimates of efficiency deduced from standard rations and experimental data.

SUMMARY.

The efficiency with which farm animals convert feedingstuffs to food for man cannot be satisfactorily estimated from liveweight increases since the food value of liveweight increase varies with the species, age and method of feeding. Nor can more than a rough estimate be made from the dry matter or gross energy of the feed consumed since these do not accurately represent the feeding value. The terms in which feed consumption and product are expressed should be similar. The basis chosen is therefore: for the feed, total dry matter, digestible nutrients and digestible energy; for the products, total edible dry matter and edible nutrients with their energy value as commonly expressed in studies of human diet. Efficiency is expressed as a percentage, dry matter related to dry matter, energy to energy, the protein of the product to the protein equivalent of the feed and the fat of the product to the non-protein digestible nutrients of the feed.

It is argued that, if feeding standards are accurate, examination of the stated feed requirements for different products will give an accurate estimate of the efficiency of production. Results of fundamental research, of the kind on which feeding standards are based, suggest that the standards for energy requirements will probably not err by more than $\pm$ 15 per cent. and that, on the average, performance will differ from expectation by much less than this. Comparison is made between expected efficiencies, as computed from rations based on feeding standards for milk production, and the efficiencies attained in metabolism experiments and practical feeding tests. The agreement is good.

The efficiency of beef production under practical experimental conditions is compared with that of continuous intensive feeding. The results are similar for baby beef, but the practice of storing cattle reduces efficiency.

The evidence regarding the effect of restricting feed consumption below that of animals fed to appetite is not conclusive. In one experiment on egg production the effect was to reduce efficiency; with pigs both positive and negative results are recorded.

Efficiency in general increases with rate of production but the increase in efficiency of protein conversion, due to higher yield, may be masked by increase in the protein of the feed. Good pasture, as sole feed, supplies more protein in proportion to the energy intake than can be used, even for milk production, and a supplement of low-protein grain would give a higher utilisation of protein.

Milk Production.—The efficiency with which cows convert the digestible energy of the production ration to milk energy is of the order of 60 per cent. The efficiency of conversion of the digestible energy of the total feed increases with milk yield, very rapidly up to an average daily yield of about 3 gallons (30 per cent. efficiency) and then less rapidly.

The partial efficiency of protein production is of the order of 56 per cent. where the protein intake is controlled. The total efficiency increases, roughly with energetic efficiency, but the rise may be masked by a high protein intake as in the grazing cow.

The practical deduction is drawn that, in herd improvement, the most rapid increase in efficiency will be got by eliminating the poorest cows.

No significant difference was found between the feeding standards considered and no conclusive evidence, taking into account the health of the cow, that the standards are too high.

Egg Production.—The partial energetic efficiency of egg production is of the order of 45 per cent. Total energetic efficiency increases with egg yield from about 8 per cent. for

120 eggs yearly to a maximum of 20 per cent. for an egg a day. The hen is, therefore, less efficient than the cow in energy conversion.

The partial efficiency of protein conversion in egg production is of the order of 68 per cent., which is above that of milk production. Total protein efficiency increases with egg yield from about 18 to about 40 per cent. It is, therefore, much lower than for milk production at low yields, and the maximum is less than the maximum for milk.

Meat Production.—Young cattle, fed for baby beef, produce with approximately maximal efficiency for both energy (9 to 11 per cent.) and protein (11 to 15 per cent.). Older cattle, first stored and then fattened, lose efficiency (8 per cent. for energy ; 9 per cent. for protein) because of the increased overhead charges for maintenance although the energetic efficiency of the fattening period alone is higher than that of baby beef (16 per cent. for energy ; 11 per cent. for protein). Continuous intensive feeding gives a steady rise in energetic efficiency with liveweight at slaughter. There is no significant difference during the fattening period between beef and fat lamb production.

Pigs, whether fed for pork or bacon, show a considerably higher efficiency of energy conversion than do cattle of any age. This is largely due to the much higher efficiency with which fat is produced from the non-protein nutrients of the ration. Indeed, in efficiency of fat production, only the pig excels the dairy cow giving 3 gallons of milk or more daily. Since the pig is still actively growing at bacon weight, the efficiency of protein conversion compares with that of baby beef of 7 cwt. liveweight and is higher than that of all other beef cattle.

Table poultry show a relatively high efficiency of protein conversion but a low efficiency of fat production. The overall efficiency of energy conversion is therefore low.

The questions of an optimum protein intake for meat production and of the validity of feeding standards are discussed.

Systems of Production Compared.—Because of the relatively high protein content and low energy value of good pasture, the stall-fed cow produces a given yield of milk more efficiently than does the grazing cow. In spite of this, the cow that calves in spring and so spends the flush of lactation on grass shows a higher efficiency for the year than does the cow that calves in autumn and spends, on unlimited grazing, the last stages of lactation and the dry period, when requirements are least.

The production of milk is so much more efficient than production of meat that the rearing of calves slightly reduces efficiency. Dairy herds producing milk, milk veal and cow beef would be roughly twice as efficient as beef herds producing prime fat beef in conversion of energy and protein and 40 per cent. more efficient in fat production.

These considerations and comparison of the performance of the individual animals justify the practice, where farming is intensive and maximum economy of production is desired, of concentrating on dairying and pig keeping.

The efficiency of the total stock population is estimated to be 4·1 per cent. for D.M., 8·7 per cent. for energy ; 11·1 per cent. for protein and 3·3 per cent. for fat conversion. This is of the order to be expected from the relative numbers of the several animals. Against the low return must be set the fact that feed, not directly utilisable as human food, is converted into food of high value and that even those feeds which can be used for direct consumption are improved in quality.

Review of Other Estimates.—Other estimates of the efficiency of individual processes and comparisons of the different classes of stock have been discussed. When these estimates are recalculated to a common basis, much evidence has been found to support, and none to invalidate, the above conclusions.

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APPENDIX.

NOTES ON THE ESTIMATES.

The figures throughout refer to or are considered to be applicable for the calendar year 1938. The estimates are based on Ministry of Agriculture Statistics (1938), Trade Statistics (Customs and Excise, 1939), with supplementary information from the Reports of the Imperial Economic Committee (1938), the Food (Defence Plans) Department (1938) of the Board of Trade, and other sources, including unpublished information from the Rowett Research Institute.

Where information could be found only for part of the United Kingdom, common knowledge of the conditions was used and the existing estimate increased to give an estimate for the United Kingdom. Some of these estimates may, of course, be in error.

Feedingstuffs Supply (Table XXXI).

The Ministry returns of crop yields have been used except for roots, for which the official figure is generally believed to be low. An increase has been made to the level of yield believed to be usual.

Allowances for direct consumption as human food of cereals and potatoes have been made in accordance with the latest dietary survey results.[1] Seeding allowances have been made throughout. For cereals used in brewing and distilling deductions have been made and partitioned between home production and imports in accordance with the indications given in the Brewers' Almanack (1940). No deduction has been made for waste.

The net imports of feedingstuffs have been assessed from the (Customs and Excise) Annual Statement of the Trade of the United Kingdom for 1938.

No account has been taken of minor supplies of feed such as unrecorded crops, kitchen waste and minor industrial waste products. Nor has any attempt been made to assess the feed value of rough grazings. It is considered that these together will amply cover feed wastage in harvesting, storage and transport.

Requirements of Stock Population (Tables XXXII and XXXIV).

Cattle.

The total number of cows and heifers is that given by the Ministry of Agriculture for the U.K. These have been debited with the cost of maintenance for one year, at the Ministry of Agriculture standard for an 1100 lb. cow, this being assumed to be the average weight. The total milk yield has been calculated from an estimate of all milk sold off farms in Great Britain. This has been increased (1) by 10 per cent. to allow for milk used on farms, and

[1] Private communication, Carnegie U.K. Dietary Survey (1937–1939).

TABLE

FEEDINGSTUFFS

HOME PRODUCED.

Feed.	Thousand tons.								Thousand Million Calories.
	Quantity.	D.M.	P.E.	Fat.	CHO.	G.D.E.	S.E.	Non-protein Digestible Nutrients.	
Wheat : Grain	177	153·3	17·0	2·1	114·0	140·0	126·7	118·83	583·24
Offal	432	371·5	46·9	16·8	204·3	301·5	244·1	242·94	1256·05
Barley : Grain	181	154·0	13·2	2·2	114·8	136·3	129·2	119·86	567·83
Offal	80	69·6	6·8	2·4	37·4	51·4	46·6	42·92	214·13
Brewers' grains	81	72·6	10·2	4·5	28·3	51·3	39·1	38·65	213·72
Distillers' „	8	7·4	1·5	0·8	2·4	6·2	4·6	4·24	25·83
Oats : Grain	1246	1080·3	94·7	49·8	590·6	823·6	741·4	705·14	3431·12
Offal	203	183·7	7·7	4·1	88·7	107·6	92·4	98·13	448·26
Rye : Grain	10	8·7	0·9	0·1	6·5	7·9	7·2	6·73	32·91
Mixed Corn : Grain	60	52·0	5·1	0·7	38·6	47·5	43·0	40·21	197·89
Straw : Wheat	226	194·4	0·1	0·9	75·3	77·5	29·4	77·37	322·87
Barley	164	141·0	1·1	1·0	66·9	70·5	37·7	69·20	293·70
Oat	1882	1618·5	16·9	11·3	709·5	752·8	376·4	735·49	3136·16
Milk : Whole	789	101·0	25·2	30·8	37·9	140·4	134·9	108·74	584·90
Skimmed	562	52·8	18·5	0·6	28·1	52·3	46·6	29·48	217·88
Sugar Beet :									
Tops	1460	236·5	16·8	4·4	121·2	151·8	125·6	131·32	632·40
Dried pulp	110	99·0	5·7	—	77·3	84·4	66·7	77·30	351·61
Molasses	44	32·9	0·3	—	26·0	26·4	22·7	26·00	109·98
Meat and Bone Meal	39	35·3	19·3	3·8	0·2	32·9	28·2	8·94	137·06
Blood Meal	3	2·6	2·0	—	—	2·6	1·9	—	10·83
Fish Meal	84	73·1	44·5	2·8	1·0	62·2	49·5	7·44	259·13
Potatoes	384	91·4	3·3	—	68·0	72·2	71·0	68·00	300·79
Turnips and Swedes									
As swedes	15834	1820·9	110·8	—	1314·2	1456·7	1155·9	1314·20	6068·61
Mangolds : Globe	6175	815·1	24·7	—	599·0	629·9	419·9	599·00	2624·16
Kohl-rabi	107	13·6	0·5	—	8·6	9·4	8·9	8·60	39·16
Cabbage, Savoy, Kale	600	84·0	8·4	1·8	46·2	62·4	54·6	50·34	259·96
Rape	975	137·5	16·1	4·9	56·6	87·8	67·3	67·87	365·77
Peas	31	26·7	5·6	0·3	16·2	24·0	21·4	16·89	99·98
Beans	104	89·1	20·5	1·2	50·1	79·6	68·4	52·86	331·61
Vetches and Tares	670	117·3	12·1	2·0	48·2	67·7	50·3	52·80	282·04
Lucerne	344	75·7	10·3	0·3	34·1	47·5	38·9	34·79	197·86
Hay : Clover hay	2257	1941·0	110·6	27·1	794·5	1157·8	654·5	856·83	4823·39
Hay : Perm. grass	3870	3316·6	178·0	38·7	1575·1	1888·6	1431·9	1664·11	7867·91
Grass : Permanent + aftermath	11291 D.M.	11291·0	1383·1	282·3	6379·4	8694·1	7565·0	7028·69	36219·62
Grass : Rotation + aftermath	4179 D.M.	4179·0	511·9	104·5	2361·1	3217·8	2800·0	2601·45	13405·35
Total Home Produced		28739·1	2750·3	602·2	15720·3	20622·6	16801·9	17105·36	85913·71

XXXI.

ESTIMATE, 1938.

IMPORTED.

Feed.	Thousand tons.								Thousand Million Calories.
	Quantity.	D.M.	P.E.	Fat.	CHO.	G.D.E.	S.E.	Non-protein Digestible Nutrients.	
Wheat : Grain	1288	1115·4	123·6	15·5	829·5	1018·8	922·2	865·15	4244·32
Offal	1025	881·5	111·2	40·0	484·8	715·5	579·1	576·80	2980·77
Barley : Grain	661	562·5	48·3	7·9	419·1	497·7	472·0	437·27	2073·42
Brewers' grains	45+9	48·4	6·8	3·0	18·8	34·2	26·1	25·70	142·48
Distillers' ,,	22+22	40·5	8·4	4·5	13·2	34·1	25·2	23·55	142·06
Oats : Grain	78	67·6	5·9	3·1	37·0	51·6	46·4	44·13	214·97
Mixed wheat offal	599	515·1	62·0	23·4	283·3	418·1	338·4	337·12	1741·80
Rye : Grain	6	5·2	0·5	0·1	3·9	4·7	4·3	4·13	19·58
Maize : Grain	2595	2257·6	198·5	70·1	1673·8	2091·6	2013·7	1835·03	8713·61
Meal	145	126·2	11·1	3·9	93·5	116·9	112·5	102·47	487·01
Brewers' grains	9	included	above.						
Distillers' ,,	22	,,	,,						
Rice : Meal and Dust	357	325·2	25·2	41·4	144·9	273·1	258·1	240·12	1137·73
Other cereal by-prod. as barley dust	27	23·6	2·3	0·5	16·5	20·5	19·5	17·65	85·40
Sugar Beet : Molasses	300	224·1	1·8	—	177·6	179·7	154·8	177·60	748·63
Meat and Bone Meal	27	24·4	13·3	2·6	0·1	22·8	19·5	6·08	94·98
Fish Meal	8	7·0	4·2	0·3	0·1	5·9	4·7	0·79	24·58
Seeds : Durra, millet, pigeon pea, etc. (as millet)	40	35·0	3·1	1·2	19·4	26·1	23·6	22·16	108·73
Locust Beans	74	62·9	2·7	0·5	51·2	55·7	52·8	52·35	232·05
Other (sw. and unsw.)	48	omitted.							
Oilseed : Cake and Meal	1787								
Cotton-seed cake (as undecorticated)	792	696·2	137·0	36·4	175·8	430·8	329·5	259·52	1794·71
Linseed cake	275	244·2	67·7	23·9	90·8	230·5	203·5	145·77	960·26
Ground nut (decorticated)	422	378·5	174·3	28·7	85·2	368·8	308·1	151·21	1536·42
Coconut	29	25·7	4·8	2·3	12·3	23·4	22·3	17·59	97·48
Palm kernel	82	73·0	13·9	4·3	36·5	63·9	60·0	46·39	266·21
Rape seed	15	13·7	4·1	1·1	3·2	10·9	8·9	5·73	45·41
Soyabean	81	69·3	29·9	4·1	19·5	66·3	55·8	28·93	276·21
Other (as Sunflower, decort.)	91	82·3	29·3	11·1	16·6	78·5	66·0	42·13	327·03
Hay : Perm. grass	33	28·3	1·5	0·3	13·4	16·1	12·2	14·09	67·07
Total Imported		7933·4	1091·4	330·2	4720·0	6856·2	6139·2	5479·46	28562·92
Grand total		36672·5	3841·7	932·4	20440·3	27478·8	22941·1	22584·9	114,476·6

(2) in proportion to the total number of *cows* in United Kingdom on the assumption that the yield stated came from the cows of Great Britain. A pregnancy allowance has been made in accordance with the Ministry standard and no fattening ration is allowed for cow beef.

Of the calves born in the year, it is assumed (basing the assumption on the I.E.C. Report on Meat, 1938) that 1122 thousand are killed for veal at 100 lb. liveweight and each is taken to have consumed 20 gallons milk. The populations of cattle under 1 year and under 2 years, as given in the Ministry Statistics, are then debited with allowances of S.E. and P.E. sufficient for maintanance and 1 lb. increase daily for the year. In addition an excess, based on the allowance of 2 lb. S.E. per pound liveweight increase is allowed for 323 thousand baby beef slaughtered during the second year (Wood and Newman's estimate increased for United Kingdom).

Similarly, the population over 2 years of age is rationed for maintenance and an average increase of 1 lb. daily and an excess, over a suitable interval, allowed for the 1004 thousand slaughtered for beef.

In estimating the number of cow beef carcases, it has been assumed that the average number of lactations per cow is three. Opinion on this subject differs considerably. The number of lactations will be higher in beef than in dairy herds. The evidence for dairy herds has recently been presented, along with new data, by Pettit (1940). If the estimate of 3 lactations is a slight underestimate for the whole country, the estimate of efficiency of the whole animal husbandry system will be altered by an entirely insignificant amount, depending on cow beef, and the estimates of the efficiency of the cow during its whole life will be somewhat low. Correction for this would increase the superiority of the cow over other classes of stock.

Horses.

The Ministry estimate has been increased by what seemed a reasonable proportion for Northern Ireland and the consumption of S.E. and P.E. is based on Ministry advice and the Scandinavian data of Jespersen (1939). Assuming an average weight of about 14 cwt. the energy requirement was calculated and the protein consumption deduced, assuming the horses pastured for 6 months and stall-fed on hay and concentrates for 6 months.

Sheep.

It was considered impossible to use the population statistics for sheep (and pigs) for the purpose of estimating requirements since these populations grow, are slaughtered and are replaced so rapidly. The device of following the growth and slaughter of the population was therefore adopted for both and the results checked against relevant data.

First, from an estimate of the distribution of sheep between lowland and hill grazings and the lambing rates in these areas, it was calculated, in consultation with Mr. A. Crichton, that the 12,318 thousand ewes in the United Kingdom would produce 11,365 thousand lambs. Of these 4106 thousand (nearly a third of the original breeding flock) would be kept for replacement ; 10 per cent. of the remainder, 726 thousand, slaughtered as milk lamb and the remainder at an average liveweight of 100 lb. as "lamb." The breeding stock replaced (4106 thousand) would supply "mutton." The total slaughterings, 11,365 thousand, are in good agreement with the I.E.C. Report on Meat (1938).

The total ewe flock is allowed a maintenance ration for the year of 10·25 lb. S.E. and 0·48 P.E. weekly, and an average milk yield of 35 gallons per ewe with lamb is provided for by an additional 4 lb. S.E. and 1·0 lb. P.E. per gallon. It does not appear to be common practice to make a pregnancy allowance to ewes. The replacement stock has been rationed for a year ; the feeder lamb for 12 weeks.

TABLE XXXII.

BASIS OF ESTIMATION OF REQUIREMENTS OF STOCK POPULATION.

	Av. Liveweight.	S.E.	P.E.	Notes.
CATTLE.				
Cows and heifers	1100 lb.	6·5 lb.	0·70 lb.	Daily maintenance requirement.
Milk production		2·5 ,,	0·60 ,,	Per gallon of milk.
Pregnancy allowance		91·0 ,,	27·3 ,,	Total for 3 months.
Cattle under 1 year	About 330 lb.	5·0 ,,	1·0 ,,	Daily maintenance and 1 lb. or more liveweight increase.
Excess for baby beef	560 lb. at end of 1st year	230·0 ,,	46·0 ,,	Total for extra live weight increase.
Cattle under 2 years	About 730 lb.	7·0 ,,	1·375 ,,	Daily maintenance and 1 lb. liveweight increase.
Excess for baby beef	8 cwt at slaughter	306·0 ,,	38·0 ,,	Total for extra liveweight increase to slaughter at 18 months.
Cattle over 2 years	10 cwt.	9·25 ,,	1·5 ,,	Daily maintenance and 1 lb. liveweight increase.
Excess for fat beef cattle	10·7 cwt. at slaughter	229·6 ,,	—	Total for extra liveweight increase.
	12·5 cwt. at slaughter	270·6 ,,	—	
HORSES.	14 cwt.	12·3 ,,	2·6 ,,	Daily maintenance and work.
SHEEP.				
Ewes	125 lb.	10·25 ,,	0·48 ,,	Maintenance weekly.
Milk production		4·0 ,,	1·0 ,,	Per gallon of milk (35 gal. per lamb ; 11,365 thousand lambs).
Rams, full grown	180 ,,	13·0 ,,	0·7 ,,	Maintenance weekly.
,, still growing	140 ,,	14·0 ,,	1·75 ,,	Maintenance and growth, weekly.
Milk lambs	Slaughter wt. 80 lb.	85·3 ,,	21·6 ,,	Total extra for ewe and lamb.
Feeder lambs	Slaughter wt. 100 lb.	137·4 ,,	22·7 ,,	Total for 12 weeks.
Replacement stock	About 100 lb.	11·0 ,,	1·75 ,,	Maintenance and growth, weekly.
PIGS.				
Sows	300 lb.	2197·0 ,,	449·0 ,,	Total for 1 year (2 litters : average 7 pigs weaned per litter).
Boars	300 lb.	2·7 ,,	0·55 ,,	Maintenance daily.
Replacement stock	100 ,,	2·6 ,,	0·5 ,,	Maintenance and growth, daily.
Pork pigs	160 ,, at slaughter	260·0 ,,	54·0 ,,	Total, weaning to slaughter.
Bacon pigs	220 lb. at slaughter	450·0 ,,	92·0 ,,	Total, weaning to slaughter.
POULTRY.				
Laying birds (light)	4 lb.	50·1 gm.	7·8 gm.	Maintenance daily.
,, ,, (heavy)	5·5 lb.	59·1 ,,	9·9 ,,	,, ,,
Egg production		38·0 ,,	10·0 ,,	Per egg.
Growing stock :				
Light breeds		16·1 lb.	2·9 lb.	Total to 4 lb. liveweight.
Heavy breeds		20·9 ,,	3·7 ,,	,, 5·5 ,, ,,
Table birds :				
Spring chicken	3·75 lb. at slaughter	7·2 ,,	1·4 ,,	Total to 15 weeks.
Fat cockerels	4·75 lb. at slaughter	11·4 ,,	2·0 ,,	,, 18 ,,

Pigs.

A similar process of reasoning gave the following estimates for pigs. Total sow population 521 thousand: assuming each rears two litters, each of 7 pigs, that gives a total of 7294 thousand young pigs. If 124 thousand be required for replacement, the remainder to be slaughtered would be 7170 thousand. Since bacon is produced chiefly (or wholly) by specialist

TABLE XXXIII.

BASIS OF ESTIMATION OF PRODUCE OF STOCK POPULATION.

	Composition of Edible Material.				Notes.	
	D.M. per cent.	Protein per cent.	Fat per cent.	CHO per cent.		
Milk:						
Whole milk	12·4	3·4	3·5	4·8	Total yield, 1768 million gallons, of which 177 million gallons fed to stock and 249·4 million gallons skimmed milk fed to stock or wasted. Net whole milk: 1591 million gallons. Skimmed milk to be deducted, 249·4 million gallons.	
Skimmed milk	9·4	3·5	0·1	5·0		
	gm.	gm.	gm.			
Eggs	12·5	6·8	5·5		4670 millions, average weight 2 oz.	
	lb.	lb.	lb.	lb.	Liveweight at Slaughter.	No. slaughtered: Thousands.
Meat:						
Veal (including edible offal)	9·2	7·9	1·3	—	100 lb.	1122
Baby beef ,, ,,	248·1	79·4	168·2	0·4	8 cwt.	323 [1]
Beef ,, ,,	371·3	99·8	270·9	0·6	10·7 cwt.	502 [1]
,, ,, ,,	443·4	114·6	328·1	0·7	12·5 ,,	502 [1]
Cow beef ,, ,,	251·3	90·1	160·6	0·6	11 ,,	884 [2]
Mutton ,, ,,	33·50	9·99	23·44	0·07	140 lb.	4106
Milk lamb ,, ,,	19·30	5·71	13·55	0·04	80 ,,	726
Lamb ,, ,,	24·12	7·14	16·93	0·05	100 ,,	6533
Bacon ,, ,,	75·5	16·8	58·5	0·2	220 ,,	2390
Pork ,, ,,	49·4	12·9	36·4	0·1	160 ,,	4780
Sow pork ,, ,,	151·0	33·6	117·0	0·4	440 ,,	124
Hens: light breeds	0·53	0·35	0·18	—	4 lb.	7500
heavy breeds	0·82	0·49	0·33	—	5·5 ,,	15,000
Spring chicken	0·41	0·36	0·05	—	3·75 ,,	7000
Fat cockerels	0·70	0·42	0·28	—	4·75 ,,	10,000

[1] 1·8 per cent. to be deducted for carcase condemnation.
[2] 6·2 ,, ,, ,, ,, ,, ,,

farms, it has been taken that one third of the pigs are fed to bacon weight and two thirds killed as pork.

It was impossible to assess the requirements of sows from the indications given by the Ministry or from common practice since no attempt is made to secure requirements during lactation. The Danish basis of Jespersen and Olsen (1939) was therefore used and 2 litters yearly, each of 7 pigs weighing roughly 33 lb. at weaning, were budgeted for.

TABLE XXXIV.—TOTAL YEARLY REQUIREMENTS AND PRODUCE OF STOCK POPULATION: 1938.

	No.	Requirements: Thous. tons. S.E.	Requirements: Thous. tons. P.E.		Produce (including edible offal). Thousand tons. D.M.	Prot.	Fat.	CHO.	Calories. Thou. mill.
Cows and heifers	3835 thousand	4061·9	437·4	Milk and milk products: net	775·3	202·3	247·3	285·0	4370·7
Pregnancy allowance	3835 ,,	155·6	46·7						
Milk, gallons	1768 million	1971·3	473·1						
Veal calves	1122 thousand	Milk only.	Included in milk fed to stock	Veal	4·6	4·0	0·7	—	22·6
Cattle under 1 year	1841 ,,	1500·0	300·0						
Baby beef	323 ,,	33·1	6·6						
Cattle under 2 years	1792 ,,	2044·0	401·5						
Baby beef	323 ,,	44·1	5·5	Baby beef	35·1	11·2	23·8	0·06	272·1
Cattle over 2 years	1294 ,,	1950·4	316·3						
Beef cattle	502 ,,	51·4	—	Beef	81·6	21·9	59·6	0·13	655·4
,, ,,	502 ,,	60·6	—	,,	97·5	25·2	72·1	0·15	788·0
Beef cows	884 ,,	No extra allowance		Cow beef	92·9	33·3	59·4	0·22	701·6
Total for cattle:		11872·4	1987·1	*Total for cattle:*	1087·0	297·9	462·9	285·56	6810·4
Horses	1110 thousand	2224·8	470·3						
Ewes	12318 ,,	2939·3	137·6	Mutton	61·3	18·3	42·9	0·13	482 8
Milk, gallons	398 million	710·0	177·5						
Rams, full grown	400 thousand	121·1	6·5						
,, growing	120 ,,	39·1	4·9						
Milk lambs	726 ,,	27·6	7·0	Milk lamb	6·2	1·8	4·4	0·01	49·3
Feeder ,,	6533 ,,	400·3	66·1	Feeder lambs	70·3	20·8	49·3	0·15	553·9
Replacement stock	4106 ,,	1051·5	167·3						
Total for sheep:		5288·9	566·9	*Total for sheep:*	137·8	40·9	96·6	0·29	1086·0
Sows	521 thousand	510·5	104·3	Sow pork	8·4	1·9	6·5	0·02	69·0
Boars	37 ,,	16·3	3·3						
Replacement stock	124 ,,	52·5	10·1						
Pork pigs	4780 ,,	554·3	115·1	Pork	105·3	27·5	77·6	0·21	849·5
Bacon pigs	2390 ,,	479·7	98·1	Bacon	80·5	17·9	62·4	0·21	665·3
Total for pigs:		1613·3	330·9	*Total for pigs:*	194·2	47·3	146·5	0·44	1583·8
Laying birds:									
Light breeds	13 million	233·8	36·4	Hens, light breeds	1·8	1·2	0·6	—	10·6
Heavy ,,	26 ,,	551·6	92·4	,, heavy ,,	5·5	3·3	2·2	—	34·6
Egg production	4770 ,,	178·2	46·9	Eggs	57·6	31·5	25·5	—	369·1
Growing stock:									
Light breeds	8 ,,	57·4	10·3						
Heavy ,,	16 ,,	149·1	26·4						
Table birds:									
Spring chickens	7 ,,	22·5	4·4	Spring chickens	1·3	1·1	0·2	—	6·2
Fat cockerels	10 ,,	50·8	8·9	Fat cockerels	3·1	1·9	1·2	—	19·6
Total for poultry:		1243·4	225·7	*Total for poultry:*	69·3	39·0	29·7	—	440·1
Grand Total:		22242·8	3580·9	*Grand Total:*	1488·3	425·1	735·7	286·3	9920·3

	D.M.	Energy.	Protein.	Fat.
Overall efficiency: per cent.	4·1	8·7	11·1	3·3

Male breeding stock were allowed only a maintenance ration and replacement stock a ration for maintenance and growth but not fattening. Pork and bacon pig requirements were derived from the experimental feeding results shown in Tables XXV and XXVI.

Poultry.

Since little information could be found on the feed requirements and rate of growth of other classes of poultry, the entire population has been taken as fowls.

It is assumed on the basis of various estimates for England and Wales and Great Britain that the total poultry population of the United Kingdom may be of the order of 80 million birds. Of these, at the beginning of the poultry year, roughly 39 million would be laying birds: 13 million of these would be of light and 26 million of heavy breeds. From the probable hatch of 48 million or more, 24 million pullets would be required for replacement, one third light breeds and two thirds heavy; of the remainder 17 million would probably be reared for table birds, possibly 7 million as "spring chickens" without special fattening, and 10 million fattened. In addition there would be some 7·5 million light and 15 million heavy fowls available as table birds.

The requirements budgeted for are in accord with these assumptions and that of an average egg yield per annum of about 120 per laying bird. This estimate is that of average expectation and is in agreement with the Food (Defence Plans) Department's estimate of total home produced eggs consumed in the United Kingdom and with the I.E.C. Report on Dairy Produce (1938), allowing 100 million eggs for a hatch of 48 million or more chicks. Average weights for light and heavy breeds have been used and the requirements for table birds estimated, using Ministry (1936) rations and stated feed consumption for rearing and fattening.

Produce of Stock Population (Tables XXXIII and XXXIV).

The mode of derivation of the estimates of produce has been similar throughout. Data on yield and composition of edible meat have been taken from the analytical data of Haecker for veal; Wood and Newman for beef; Wood for sheep; Rowett Research Institute (unpublished information) for pigs, and Harshaw for poultry.

Edible offal, including suet and lard, not sold with the carcase, have been estimated separately. (See also p. 12.)

Allowances have been made for carcase condemnation in cattle on the basis of the Report of the E.A.C. Committee on Cattle Disease, Cmd. 4591 (1934) and information from a local knackery which covers the County of Aberdeen. This information and that from the local Bacon Factory indicates that carcase condemnation of sheep and pigs is negligible.

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